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Title Page

The impact of airplane noise on mental and physical health. A quasi-experimental analysis.

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Abstract

Objectives. Historically, departures at New York City's La Guardia airport (LGA) flew over a large sports complex. During the US Open tennis games, flights were diverted to fly over a heavily populated foreign-born neighborhood for roughly two weeks out of the year so that the tennis match was not disturbed (the "TNNIS" departure). In 2012, the use of the TNNIS departure became year-round to better optimize flight patterns around the metropolitan area.

Methods. We exploited exogenously-induced spatial and temporal variation in flight patterns in order to examine difference-in-difference effects of this new aircraft noise on the health of individual residents in the community relative to individuals residing within a demographically similar community that was not impacted. We used individual-level Medicaid records, focusing on conditions associated with noise: sleep disturbance, psychological stress, mental illness, substance use, and cardiovascular disease.

Results. We found that increased exoposure to airplane noise was associated with a significant increase in insomnia across all age groups, but particularly in children ages 5-17 (OR = 1.64). Cardiovascular disease increased significantly both among 18-44-year-old (OR = 1.45) and 45-64-year-old Medicaid recipients (OR = 1.15). Substance use and mental health-related emergency department visits also increased. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Conclusion. This study demonstrates that increased cardiovascular disease, substance use/mental health emergencies, and insomnia among local residents are the externalities of this decision.

What is already known about this subject?

Previous work demonstrated adverse health effect associated with airplane noise, including cardiovascular disease and insomnia.

What are the new findings?

This study exploits exogenous variation in exposure to airplane noise longitudinally in a case and control community in New York City using individual-level Medicaid records. Our more granular and higher quality data suggest that the increased airplane noise was associated with increases in insomnia, substance use/mental health emergencies, and cardiovascular disease.

How might it impact on policy in the foreseeable future?

As air traffic increases, policy makers should consider avoiding residential areas when designing new airports.

When aircraft enter urban airspace, they traditionally approach and depart over areas that are less populated, such as waterways, parks, or areas with warehouses or manufacturing.[1] However, as air traffic increases over time, the airspace used for traditional routes of arrivals and departures has become crowded.[2] To handle this increase in traffic, landings and departures must sometimes be altered to optimize flight patterns.[2] Almost invariably, these new flight patterns require routing aircraft over populated areas that were not previously exposed to aircraft noise.

Noise, and aircraft noise in particular, is associated with a number of health problems, particularly sleep disturbances, mental illness, and substance use.[3-8] The sleep disturbances and psychological stress associated with aircraft noise are, in turn, thought to produce a cascade of biological effects that result in premature aging via endocrinologic changes.[9-14]

Noise is thought to produce stress by activating the central nervous system and by interfering with sleep.[3,6,8,15,16] This stress produces predictable changes in biochemical pathways in human and animal studies that accelerate the rate of aging.[14,17,18] This accelerated aging process has been linked to the premature onset of age-related diseases, including cardiovascular disease.[9,19,20]

While the pathways linking poor sleep and psychological stress to premature aging and chronic disease are understood, few studies have examined interventions that alter noise exposure in human populations.[21] Most of our knowledge about the health impact of aircraft noise in humans is based upon associational studies.[7] These studies suffer from a number of limitations. On one hand, people who live near airports may self-select, such that those who are less sensitive to noise can take advantage of lower home prices on purchases or rentals for homes.[13,19,20] On the other hand, those who live near airports tend to have lower than average income, a major risk factor for premature disease and death.[19,22-24] There is limited evidence based of the impact of aircraft noise on premature aging and health based on experimental or quasi-experimental analysis.[12,13,23,25]

Flight pattern changes afford a unique opportunity for studying the health impact of aircraft noise in humans. In the past decade, flight patterns have shifted, and these shifts have increasingly been accompanied by resident complaints.[26] As they do so, it becomes possible to identify areas that are impacted by new aircraft noise.

We conducted a longitudinal case/control study of one well-documented flight pattern change in New York City. LaGuardia Airport is one of 3 major airports in the greater New York City area. One of its departure patterns utilizes Flushing Meadows Park, a route known as the "Whitestone Climb." [24] Because it is over greenspace, the Whitestone Climb has little impact on humans living in nearby dwellings. However, this park is also the location of the US Open Tennis match. During games, a seldom-used departure route called the "Flushing Climb" (now called TNNIS) was used so that the tennis games were not disturbed by aircraft noise. The TNNIS climb routes aircraft over densely populated Flushing, Queens, greatly increasing the exposure of residents to noise on the ground.[24]

A Freedom of Information Act (FOIA) request by a local group opposed to airplane noise in Queens demonstrated that flight patterns using the TNNIS climb have increased to year-round use since 2012. Before that time, the use of the TNNIS climb was rare outside of the US Open.[27]

Previous work found that the year-round use of the TNNIS climb was costly, both in terms of money and lives.[24] However, this economic analysis was primarily based on associational data. Using data on flight patterns over Flushing obtained using the FOIA as well as Medicaid utilization data, we conducted a quasi-experimental analysis of the health impacts of the airplane noise associated with this new route.

Methods

Data

The data used in this study are New York City Medicaid claims prepared by the New York University Health Evaluation and Analytics Lab. The data include Medicaid member demographic information, address history, eligibility, medical services, and diagnostic information. The database consists of Medicaid fee for service claims and managed care encounters; both are comparable in quality.[28]

A priori specifications and hypotheses

We hypothesized that exposure to airplane noise would increase health care utilization, insomnia, mood disorder, anxiety, depression, and cardiovascular disease depending upon the age group.[3,6,8,9,12,13] Specifically, exposure to airplane noise would produce sleep disorders across all age groups,[29] would lead to emotional or behavioral disturbances including substance abuse, mood disorder, depression, and developmental disorders among young adults aged 18 to < 45 years who tend to be more at risk of these stress-associated disorders,[30] and would produce or exacerbate cardiovascular disease among older adults aged 45 and over when heart disease begins to increase in prevalence.[31] Noise studies suggest wide-ranging pscychoneuroendocrinological effects (allostatic load) producing hypertension, hyperglycemia, and hypercholesterolemia.[3,6,8,9,12,13,30,31] These biological changes are linked to cardiovascular disease, a correlate of exposure to airplane noise as well as other forms of nighttime noise.[7,10,11,32]

Study Design

We used individual-level data at the member-cohort level for the analysis. We selected samples of Medicaid members residing in each of the two neighborhoods at two points in time.

147 The pre-cohort was defined as Medicaid recipients living in the study neighborhoods between 2019-2011 (pre cohort) and 2013-2016 (post cohort). 64% of the Flushing pre cohort and 63% of the Sunset Park pre cohort were also in the post cohort. We used the difference-in-difference models to analyze the results.

151 Exposure

152 To determine exposure, we used data extracted under a FOIA request for flight patterns over Flushing, Queens, New York and from Part 150 Study Technical Advisory Committee Meeting No. 8 documents.[33] These documents were derived from a 2014 study conducted and funded by the Port Authority of NY & NJ (Port Authority) in partnership with the Federal Aviation Administration (FAA). In these documents the Port Authority presents estimated noise exposure in geographies surrounding La Guardia Airport. Exposure is quantified using the Integrated Noise Model in DNL (day-night average sound level) units. We also visually inspected changes in sound related to aircraft flight over sound monitors on the ground in Flushing using Flight Aware, a publicly-available flight tracking website.[34]

161 These geographic regions or corridors were stratified according to intensity of noise exposure over a 24-hour period. We divided census tracts into > 60 DNL, 55-60 DNL, and <55 DNL (Figure 1). We aggregated census tracts and for regions of Flushing, Queens with noise exposure levels of 55 DNL or greater after 2012.[19] These tracts after 2012 are therefore identified as the treatment condition in this quasi-experimental analysis.

166 Flushing, Queens is a vibrant, predominantly immigrant neighborhood.[24] It is increasingly populated by Asians immigrants, particularly those of Chinese descent. The English proficiency in 2018 was 49%, and the population was 54% Asian and 26% white. While the

neighborhood ranked as one of the poorest, the rates of education are higher than average and the rates of crime, obesity, and hypertension are much lower than New York City as a whole.[24]

Sunset Park in Brooklyn, New York was identified as an appropriate control neighborhood as the neighborhood (1) did not experience a change in exposure to aircraft noise after 2012 when the TNNIS climb began frequent use, and (2) is similar to Flushing with respect to the distribution of sociodemographic and economic characteristics.[35,36] Like Flushing, Sunset Park is increasingly populated by those of Chinese descent with 32% of the population identifying as Asian and 23% identifying as white. About 48% of the residents were born outside of the United States and the English proficiency in 2018 was 51%.[25] Sunset Park also has high poverty rates with relatively low rates of crime, obesity, and hypertension, and high levels of education relative to New York City as a whole.[24] Census tracts in Sunset Park were matched to those identified in Flushing based on race, foreign-born status, and age distribution.

Key outcomes

We used International Classification for Disease revision (ICD-9 and ICD-10) codes as well as Clinical Classifications Software (CCS) codes for diagnostic groups to identify the following conditions of interest: insomnia (ICD-9 = 3270, 78052 or ICD-10 = G470), cardiovascular disease (CCS = 109 – 113), alcohol use disorder (CCS=660), substance use disorder (CCS = 661), anxiety (CCS = 651), depression (ICD-9 = 311 or ICD-10 = F33), mood disorder (CCS = 657), and disorders usually diagnosed in infancy, childhood adolescence (CCS = 655), which includes autism, childhood emotional disorder, and separation anxiety.

We linked census tracts of Flushing and Sunset Park to geocoded Medicaid addresses. If a recipient had a Medicaid-registered address within a given census tract, they were assigned to that census tract. Participants were excluded if they had invalid addresses, dual Medicare status, did not have a valid date of birth, or were not officially enrolled in Medicaid during the study period (Table 1). Participant samples were then defined as Medicaid recipients in the period 2009-2011 (pre-implementation period) and 2013-2015 (the TNNIS use period) and who resided within census tracts in Flushing and Sunset Park.

For these identified records, indicator variables were created to identify type of medical claims inpatient, outpatient, and emergency department (ED) visits as well as prescription drugs, both overall and for visits related to substance use and mental health disorders (650-663, 670). We additionally obtained information on the age of the subscriber associated with each record. Because we did not have access to Medicare records, and did not include dual eligible participants due to the high likelihood of pre-existing medical conditions and smaller sample size, our sample does not include adults aged 65 or older. Age in years was defined as the calculated age on January 1, 2009 and January 1, 2013, and stratified into three age cohorts, 5-17, 18-44, 45-64 years.

Statistical analyses

Our focus is on the rate of diagnoses for the hypothesized conditions. We first assess whether there were significant changes in utilization overall between the baseline and TNNIS use periods and whether the observed changes differed by neighborhood (i.e., exposure) after considering other changes over time between these neighborhoods. We use Poisson regression (see equation 1) to model the number of overall and substance use and mental health related inpatient, emergency department and outpatient visits for those months in which participants were enrolled in Medicaid.

For our primary analyses, we use logistic regression (see equation 2) to examine the odds of receiving a diagnosis for the hypothesized conditions. Before implementing these regression

215 analyses, we examined trends in socio-demographic characteristics as well as trends in Medicaid enrollment to ensure that no divergent patterns were noted around 2012. Because racial composition varied somewhat between the two neighborhoods (Table 1), we controlled for race in our analyses to ensure that compositional changes by race did not influence the analysis. We also stratified by age so that we could better test our *a priori* hypotheses by condition. For chronic diseases, i.e. cardiovascular disease, we adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation.

$$\log\left(E(Y \mid \boldsymbol{x})\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (1)$$

$$where\ Y = number\ of\ Medicaid\ claims\ for\ condition\ of\ interest$$

$$offset = number\ of\ Medicaid\ enrollment\ months$$

$$\log\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (2)$$

$$where\ p = \Pr(Y = 1)\ is\ the\ probability\ of\ having\ Medicaid\ claim\ for\ condition\ of\ interest$$

Here, x_1, was the indicator for neighborhood exposure condition (Sunset Park=0 vs Flushing=1); x_2, indicated implementation period (pre-implementation=0 vs TNNIS implementation=1); and x_3, race/ethnicity group membership (Asian=1, Black=2, Hispanic=3, White=4 [reference], Other=5, Unknown=6).

Patient and Public Involvement

The research question was inspired by the work of a non-profit community organization called Queens Quiet Skies that works to mitigate airplane noise. One of the coauthors of the paper was a member of this organization and obtained the Freedom of Information Act requests for Federal Aviation Administration documents. These documents were used to identify the treatment census tracts and measuring the level of airplane noise exposure.

Results

Participants were generally similar across both groups over the two points in time (Table 1), but health care utilization varied over time by age group and treatment status.

The increased use of the TNNIS climb occurred in 2012.[27] Prior to that date the climb was only used for the US Open or unexpected weather/runway repairs.[27] We were only able to obtain data on TNNIS departures after the New York Port Authority's Fiscal Year 2013 because the Port Authority indicated that the earlier data had been lost. There were roughly 1,278 TNNIS departures/year on average during US Open events in the 2013-2019 period, providing a point of reference. Since 2013, the total annual number of TNNIS climbs ranged from between 9,349 and 29,676, with an average of 18,653/year. The DNL figures (Figure 1) reflect the average noise exposure by census tract across the 2013-2019 period, and may not reflect the actual change in aircraft noise in Flushing, NY in the pre-2012 and post-2012 periods.

Overall medical utilization

Table 2 provides results from regression models assessing period-related changes in medical utilization and diagnoses. The effects of the change in flight patterns on overall utilization were inconsistent across types of utilization and age. Overall, outpatient visits increased slightly in Flushing relative to Sunset Park for those aged 18-44 (rate ratio [RR] = 1.04, 95% CI = 1.04, 1.05). Prescription drug claims also increased by a similar amount for this group (RR = 1.06, 95% CI = 1.06, 1.06). However, outpatient visits and prescription drug use for children in Flushing aged 5-17 (outpatient RR=0.86, 95% CI = 0.85, 0.87; prescription drug claims RR = 0.94, 95% CI = 0.94, 0.95) as well as for older adults 45 – 64 declined (outpatient RR=0.92, 95% CI = 0.92, 0.93; prescription drug claims RR = 0.93, 95% CI = 0.92, 0.93).

While the general pattern for outpatient visits indicates decreased medical utilization in Flushing compared to Sunset Park over time, emergency department visits in Flushing increased in the post TNNIS period among all age groups. For ages 5-17, the RR was 1.31 (95% CI= 1.24, 1.37); for ages 18-44, the RR was 1.45 (95% CI = 1.41, 1.49); and for ages 45-64, the RR was 1.16 (95% CI = 1.11, 1.21). Substance use and mental health-related emergency department visits also increased in Flushing in the post period relative to Sunset Park, with rate ratios ranging between 2.5 to 4.1. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Relative to Sunset Park, inpatient visits in Flushing also show statistically significant increases for overall visits for ages 18-44 (RR=1.05, 95% CI = 1.02, 1.08). However, statistically significant decreases were observed for ages 45-64 (RR=0.93, 95% CI = 0.88, 0.97).

Changes by diagnosis

Relative to Sunset Park, implementation of the TNNIS climb was associated with increases in insomnia diagnoses, particularly for children. For example, the crude prevalence of insomnia for children increased by 57% from 398 per 100,000 in Flushing, compared to a 6% decrease from 477 per 100,000 in Sunset Park. For children in this age group, the odds ratio (OR) for insomnia was 1.64 (95% CI =1.12, 2.39). For older ages, the effect sizes were somewhat less striking (i.e., for the 18-44 age group, the OR was 1.17 [95% CI = 1.09, 1.26], and for ages 45-64 the OR = 1.1 [95% CI = 1.09, 1.28]).

Cardiovascular disease diagnoses increased significantly in Flushing relative to Sunset Park in the post-2012 period. For 18-44-year-olds, the crude prevalence of cardiovascular disease increased in both neighborhoods due to aging of the samples, by 83% from 1,955 per 100,000 in Flushing and by 29% from 1,576 per 100,000 in Sunset Park. The OR for cardiovascular disease diagnoses in Flushing relative to Sunset Park in this age group was 1.45 (95% CI = 1.30, 1.62). For 45-64-year-olds, , the crude prevalence increased by 33% from 9,934 per 100,000 in Flushing and 19% from 9,073 per 100,000 in Sunset Park. For this age group, the OR was 1.15 (95% CI = 1.07, 1.25). Substance use disorder only increased significantly for the 45-64 age group in Flushing relative to Sunset Park (OR =1.24, 95% CI=1.07, 1.44).

Figure 2 shows the monthly prevalence of insomnia and cardiovascular disease diagnoses for the 45-64 age group. Age is measured at the beginning of each period, January 1, 2009 for the pre-period and January 1, 2013 for the post period. The numerator is the number of unique individuals with one or more diagnosis from inpatient, emergency room or outpatient claims and the denominator is the number of Medicaid-enrolled patients. The trends of both conditions increased throughout the study periods, because people are getting older, but Flushing showed increases that were larger in magnitude in the post period relative to Sunset Park.

Results for other conditions were more mixed. Clinical depression diagnoses increased for the two older age groups (ages 18-44 OR = 1.12, 95% CI = 1.02, 1.24; ages 45-64 OR = 1.20, 95% CI = 1.08, 1.33). Broader mood disorder diagnoses, however, only showed statistically significant increases for the 45-65 age group (OR = 1.10, 95% CI = 1.00, 1.20). For 5-17-year-olds, developmental disorder diagnoses significantly decreased (OR=0.80, 95% CI = 0.66, 0.97) in Flushing relative to Sunset Park after the implementation of TNNIS.

Discussion

We find that increases in airplane noise at DNL levels greater than 55 were associated with increases in insomnia, depression, substance abuse, and cardiovascular disease across most age groups. These diagnoses are generally consistent with our *a priori* hypotheses regarding the relationship between exposure to airplane noise and health.[3,6,8,9,12,13,30,31] Specifically, airplane noise may produce disruptions in sleep and psychological stress, thereby producing neuroendocrine disruptions that lead to mental health disorders and cardiovascular disease.

Our study was subject to a number of limitations. First, the health effects in a predominantly Chinese-American population may not be generalizable to other populations. Chinese-Americans in New York City are unusually healthy.[37] Medicaid data also present unique challenges. Participants can enter and exit the program, for example. If there are more participants exiting the program in one area relative to another, the observed outcomes will also change. We addressed this problem by adjusting for the months a participant was enrolled in Medicaid within a calendar year, but noise may nevertheless be introduced in the analysis. Finally, it is possible that the change in neighborhood composition over time differed before and after the implementation of year-round TNNIS departures in Flushing relative to Sunset Park. However, we did not observe any trends in the available data that suggested this was the case, and there were no major events in 2012 that clearly serve as an alternative causal factor for either the primary or unexpected findings.

The biological pathways through which airplane noise impacts health have been elucidated.[9-14] Numerous associational studies suggest that airplane noise produces real-world health impacts, and experimental animal models show a wide range of health impacts associated with noise-induced stress as well.[3-9,11-13,15-18,32] Our study adds quasi-experimental evidence in humans to this substantial body of research showing that increasing airplane noise will have detrimental health impacts on communities surrounding airports. The magnitude of our findings is not strictly comparable to those in associational studies because lagged health effects (e.g., the time required for psychological stress to manifest as cardiovascular disease) tend to mute the measured impacts.

Nevertheless, the magnitude of the impact of airplane noise on the health outcomes we observe are generally in line with associational studies. For instance, an earlier analysis of associational studies of the health impact of aircraft noise in Flushing, NY estimated that aircraft noise would produce a weighted increase in cardiovascular disease of 14% (RR = 1.14, 95% CI = 1.08, 1.22) and a weighted increase in anxiety of 79% (RR = 1.79, 95% CI = 1.0-3.1).[11,24] We observe an odds ratio for cardiovascular disease among 18-64-year-olds in the range of 1.12 to 1.40. While the studies examine incident cardiovascular disease and we measure both incident and prevalent cardiovascular disease, it is reasonable to assume that the OR we estimate does not greatly overestimate the adjusted RR computed using associational studies.[38]

Cost-effectiveness analyses (based partly on earlier associational data) show that the benefits of noise-mitigation strategies (reduced illness and discomfort) tend to outweigh the costs.[24,39] Given that these earlier studies did not include the full range of health outcomes that we measure here, it is likely that these studies understate the already substantial benefits of mitigation strategies.

Much more comprehensive economic analyses are required to determine the extent to which policymakers may wish to act. The costliest options—building airports far from populated areas and providing high speed transit and freeways—can increase the cost of mitigation by billions of dollars.

Research Ethics Approval

This study is approved by the Institutional Review Borad at New York University Washington Square under IRB-FY2016-1101.

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Disclaimer: The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the New York State Department of Health. Example of analysis performed within this article are only examples. They should not be utilized in real-world analytic products.

Table 1 – Demographics characteristics and outcome prevalence and rates for Flushing, New York and Sunset Park, New York before (earlier than 2012) and after (after 2013) airplane noise increased in Flushing, New York.

Baseline Characteristics	Pre-Period: 2009-2011						Post-Period: 2013-2015					
	Age 5 -17		Age 18-44		Age 45-64		Age 5-17		Age 18-44		Age 45-64	
	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park
Demographics												
Total N	20,120	21,597	57,089	52,016	36,472	18,681	24,552	26,009	76,278	60,774	50,806	24,421
Age (Mean)	11.69	11.12	31.07	29.86	53.44	53.29	11.43	10.71	30.95	30.35	53.99	54.22
Age (STD)	3.94	3.92	8.19	7.54	5.59	5.5	3.94	3.87	7.84	7.25	5.44	5.57
Female (%)	48%	48%	58%	57%	54%	51%	48%	48%	56%	54%	54%	52%
Asian (%)	50%	46%	60%	62%	63%	60%	52%	47%	59%	59%	63%	62%
Black (%)	6%	2%	5%	1%	4%	2%	4%	1%	3%	1%	3%	1%
Hispanic (%)	17%	15%	11%	9%	11%	11%	14%	14%	7%	7%	7%	8%
White (%)	11%	24%	10%	15%	10%	14%	10%	24%	8%	14%	8%	12%
Other (%)	5%	3%	5%	4%	6%	7%	5%	3%	4%	3%	5%	6%
Unknown (%)	12%	11%	10%	8%	6%	5%	14%	12%	20%	16%	13%	11%
Average months on Medicaid per year	9	10	8	8	9	10	9	10	8	8	9	9
Total Medicaid Spending per Person per Year	$1,911	$1,904	$3,818	$3,954	$6,754	$6,076	$1,783	$1,972	$3,398	$3,914	$6,520	$6,115
Prevalence per 100,000												
Insomnia	398	477	4,208	6,096	8,036	9,143	623	450	4,755	5,873	11,034	10,843
Cardiovascular disease*	NA*	NA*	1,955	1,576	9,934	9,073	NA*	NA*	3,575	2,040	13,260	10,786

Alcohol Use Disorder	NA*	NA*	2,114	1,173	2,470	2,184	NA*	NA*	2,264	1,358	2,870	2,199
Substance Use Disorder	NA*	NA*	2,265	1,517	1,799	2,098	NA*	NA*	3,799	2,926	4,250	4,058
Anxiety	NA*	NA*	5,124	4,639	6,279	6,279	NA*	NA*	5,726	5,265	7,537	7,416
Depression	NA*	NA*	3,782	2,874	6,007	5,867	NA*	NA*	3,191	2,272	5,637	4,656
Mood Disorder	NA*	NA*	6,371	4,900	9,399	8,891	NA*	NA*	5,607	4,410	8,375	7,297
Disorders diagnosed young	1,983	1,394	289	212	170	112	2,480	2,219	307	244	163	188
Visits per 1,000 per year												
Emergency Department	328	216	335	257	288	237	375	188	360	217	332	216
Emergency Department (SM)	13	20	26	21	31	39	20	7	32	12	45	36
Inpatient Stays	70	53	267	319	299	245	60	49	231	300	234	190
Inpatient Stays (SM)	14	7	43	24	45	32	11	5	37	21	37	21
Outpatient visits per person per year												
Total Outpatient	3.4	4.1	4.1	4.6	6.7	7.3	3.9	5.2	4.5	5.5	7.6	8.2
Outpatient (SM)	0.2	0.2	0.3	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.5	0.4

* We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

Table 2 – Model Results and 95% Confidence Intervals

	Rate Ratios from the Difference in Difference Poisson Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	0.92 (0.83, 1.03)	1.05 (1.02, 1.08)	0.93 (0.88, 0.97)
Emergency Department Visits	1.31 (1.24, 1.37)	1.45 (1.41, 1.49)	1.16 (1.11, 1.21)
Outpatient Visits	0.86 (0.85, 0.87)	1.04 (1.04, 1.05)	0.92 (0.92, 0.93)
Pharmacy Claims	0.94 (0.94, 0.95)	1.06 (1.06, 1.06)	0.93 (0.92, 0.93)
	Rate Ratios from the Difference in Difference Poisson Model Substance Use and Mental Health Related		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	NA*	1.11 (1.01, 1.22)	1.19 (1.04, 1.36)
Emergency Department Visits	4.11 (3.28, 5.16)	2.46 (2.20, 2.76)	1.48 (1.31, 1.67)
Outpatient Visits	1.12 (1.09, 1.16)	0.93 (0.92, 0.95)	0.87 (0.85, 0.89)
	Odds Ratios from the Difference in Difference Logistic Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Insomnia	1.64 (1.12, 2.39)	1.17 (1.09, 1.26)	1.18 (1.09, 1.28)
Cardiovascular Disease**	NA*	1.45 (1.30, 1.62)	1.15 (1.07, 1.25)
Alcohol Use Disorder	NA*	0.97 (0.86, 1.11)	1.16 (0.99, 1.35)
Substance Use Disorder	NA*	0.92 (0.83, 1.03)	1.24 (1.07, 1.44)
Depression	NA*	1.12 (1.02, 1.24)	1.20 (1.08, 1.33)
Anxiety	NA*	1.02 (0.95, 1.10)	1.01 (0.92, 1.11)
Mood Disorder	NA*	1.03 (0.95, 1.10)	1.10 (1.00, 1.20)
Disorders diagnosed young	0.80 (0.66, 0.97)	0.99 (0.72, 1.37)	0.56 (0.31, 1.04)

*These diseases and conditions are rare or difficult to diagnose in children.

**We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

Figure 1 – Intensity of noise exposure over a 24-hour period by census tract. The day night level (DNL) 55 corridor (outer line) is demarcated separately from the DNL 60 corridor (inner line).

Figure 2 – Prevalence of insomnia and cardiovascular disease diagnoses per 100,000 among 45-64 age group

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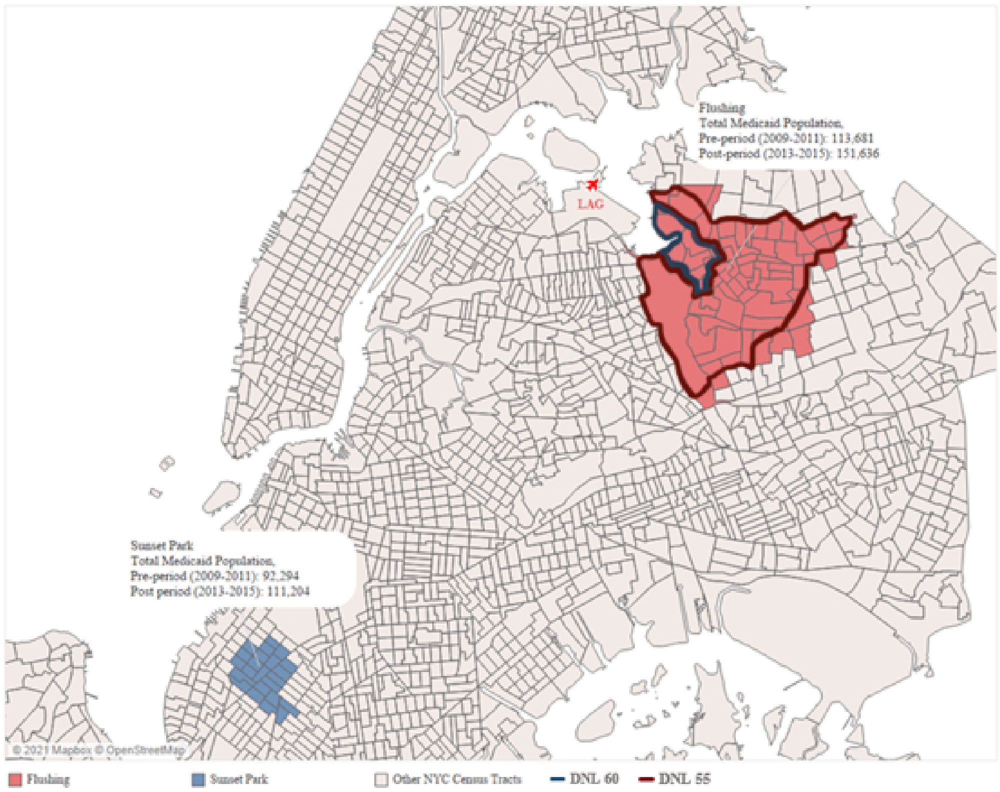

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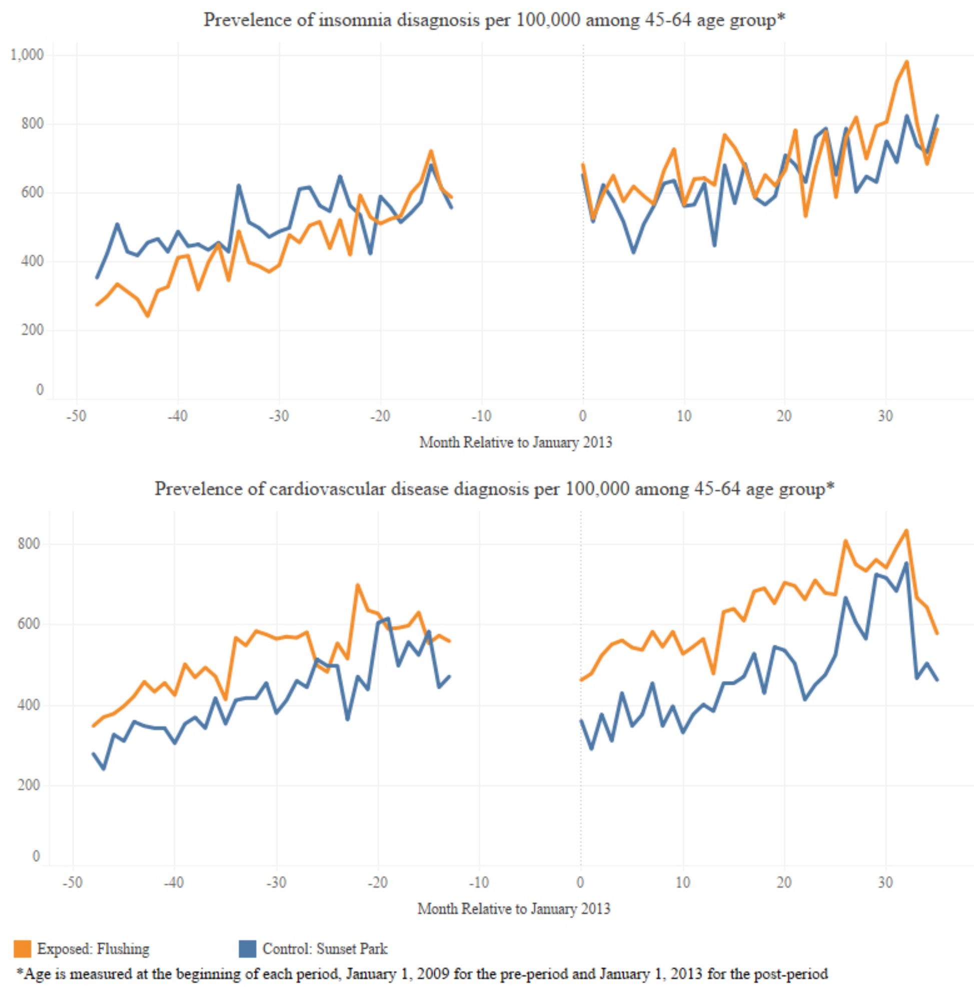

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2-3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4-6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4
Bias	9	Describe any efforts to address potential sources of bias	7, 11
Study size	10	Explain how the study size was arrived at	8, 14-15
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	7-8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	8, 14-15
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	8,14-15
Outcome data	15*	Report numbers of outcome events or summary measures over time	8-11, 14

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8-11, 14-19
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	11-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Supplemental material, acknowledgements

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Title Page

The impact of airplane noise on mental and physical health. A quasi-experimental analysis.

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The impact of airplane noise on mental and physical health: a quasi-experimental analysis.

Abstract

Objectives. Historically, departures at New York City's La Guardia airport (LGA) flew over a large sports complex within a park. During the US Open tennis games, flights were diverted to fly over a heavily populated foreign-born neighborhood for roughly two weeks out of the year so that the tennis match was not disturbed (the "TNNIS" departure). In 2012, the use of the TNNIS departure became year-round to better optimize flight patterns around the metropolitan area.

Methods. We exploited exogenously-induced spatial and temporal variation in flight patterns to examine difference-in-difference effects of this new exposure to aircraft noise on the health of individual residents in the community relative to individuals residing within a demographically similar community that was not impacted. We used individual-level Medicaid records, focusing on conditions associated with noise: sleep disturbance, psychological stress, mental illness, substance use, and cardiovascular disease.

Results. We found that increased exposure to airplane noise was associated with a significant increase in insomnia across all age groups, but particularly in children ages 5-17 (OR = 1.64). Cardiovascular disease increased significantly both among 18-44-year-old (OR = 1.45) and 45-64-year-old Medicaid recipients (OR = 1.15). Substance use and mental health-related emergency department visits also increased. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Conclusion. We find that increased exposure to airplane noise increases diagnosed cardiovascular disease, substance use/mental health emergencies, and insomnia among local residents.

Strengths and limitations

1. We used a quasi-experimental design to study before and after impacts of a flight pattern change in two matched zip code clusters within New York City (a difference-in-difference design).
2. We used a large insurance claims database that allowed us to capture diagnoses for most residents in both impacted and unimpacted zip code clusters.
3. Despite the difference-in-difference design, it is possible that participants self-segregated after the increase in aircraft noise or that other unmeasured factors influenced the observed outcomes.
4. We were unable to compute a dose-response relationship due to the use of aggregated noise data.
5. We find that a sudden and dramatic change in aircraft noise increased diagnoses of insomnia, cardiovascular disease, substance abuse, and mental illness.

What is already known about this subject?

Previous work demonstrated adverse health effect associated with airplane noise, including cardiovascular disease and insomnia using ecological or associational approaches.

What are the new findings?

This study exploits exogenous variation in exposure to airplane noise longitudinally in a case and control community in New York City using individual-level Medicaid records. Our difference-in-difference design coupled with more granular data suggest that the increased airplane noise was associated with increases in insomnia, substance use/mental health emergencies, and cardiovascular disease may be causal in nature, but additional studies must be done.

How might it impact on policy in the foreseeable future?

As air traffic increases, policy makers should consider conducting analyses on the health impacts of their policy changes and should strive to build airports further from residential areas.

Authorship Statement

Ms. Scarlett Sijia Wang, Dr. Sherry Glied, Dr. Sharifa Z. Williams and Dr. Peter Meunnig approved the final draft and agreed to be accountable for all aspects of the work. Ms. Scarlett Sijia Wang contributed to study design, data linkage, analysis, interpretation of the data, drafting the methods and results sections. Dr. Sherry Glied contributed to the acquisition of data, study design, analysis, and interpretation of data. Dr. Sharifa Z. Williams contributed to data analysis and interpretation of data. Dr. Peter Muennig contributed to study conception, study design, analysis, interpretation of data and drafting the introduction and discussion sections. Though Mr. Brian Will passed away prior to the submission of the manuscript, he had significant contributions in the study conception, the acquisition of data and sample identification.

Competing Interest

At the time of the study, Mr. Brian Will worked at a non-profit organization called Queens Quiet Skies who are a grass-roots group aiming to address airport noise.

Data Availability

We used individual-level claims data that contain protected Patient Health Information (PHI). Therefore, the data cannot be made unavailable publicly as required by the Health Insurance Portability and Accountability Act (HIPPA).

La Guardia's airspace originally utilized departures over areas that were less populated, such as waterways, parks, or areas with warehouses or manufacturing.[1] However, as air traffic increased over time, the airspace used for traditional routes of arrivals and departures became crowded and conflicted with that of a nearby airport, John F. Kennedy.[2] As with La Guardia, other airports sometimes manage increases in traffic by optimizing flight patterns with less regard for the populations on the ground.[2] Almost invariably, these new flight patterns require routing aircraft over populated areas that were not previously exposed to aircraft noise.

Noise, and aircraft noise in particular, is associated with a number of health problems, particularly sleep disturbances, mental illness, and substance use.[3-8] The sleep disturbances and psychological stress associated with aircraft noise are, in turn, thought to produce a cascade of biological effects that result in premature aging via endocrinologic changes.[9-14]

Noise is thought to produce stress by activating the central nervous system and by interfering with sleep.[3,6,8,15,16] This stress produces predictable changes in biochemical pathways in human and animal studies that accelerate the rate of aging.[14,17,18] This accelerated aging process has been linked to the premature onset of age-related diseases, including cardiovascular disease.[9,19,20]

While the pathways linking poor sleep and psychological stress to premature aging and chronic disease are understood, few studies have experimentally examined interventions that alter noise exposure in human populations.[21] Most of our knowledge about the health impact of aircraft noise in humans is based upon associational studies.[7] These studies suffer from a number of limitations. On one hand, people who live near airports may self-select, such that those who are less sensitive to noise can take advantage of lower home prices on purchases or rentals for homes.[13,19,20] On the other hand, those who live near airports tend to have lower than average income, a major risk factor for premature disease and death.[19,22-24] There is limited evidence based of the impact of aircraft noise on premature aging and health based on experimental or quasi-experimental analysis.[12,13,23,25]

Flight pattern changes afford a unique opportunity for studying the health impact of aircraft noise in humans. In the past decade, flight patterns have shifted, and these shifts have increasingly been accompanied by resident complaints.[26] As they do so, it becomes possible to identify areas that are impacted by new aircraft noise. In general, the point of maximum noise from an aircraft happens immediately after take-off as the aircraft is on full power. This is the for the experimental group in our study.

We conducted a longitudinal case/control study of one well-documented flight pattern change in New York City. LaGuardia Airport is one of 3 major airports in the greater New York City area. One of its departure patterns utilizes Flushing Meadows Park, a route known as the "Whitestone Climb." [24] Because it is over greenspace, the Whitestone Climb has little impact on humans living in nearby dwellings. However, this park is also the location of the US Open Tennis match. During games, a seldom-used departure route called the "Flushing Climb" (now called TNNIS) was used so that the tennis games were not disturbed by aircraft noise. The TNNIS climb routes aircraft over densely populated Flushing, Queens, greatly increasing the exposure of residents to noise on the ground.[24]

A Freedom of Information Act (FOIA) request by a local group opposed to airplane noise in Queens demonstrated that flight patterns using the TNNIS climb have increased to year-round use since 2012. Before that time, the use of the TNNIS climb was rare outside of the US Open.[27]

Previous work found that the year-round use of the TNNIS climb was costly, both in terms of money and lives.[24] However, this economic analysis was primarily based on associational data. Using data on flight patterns over Flushing obtained using the FOIA as well as Medicaid utilization data, we conducted a quasi-experimental analysis of the health impacts of the airplane noise associated with this new route. In the United States, Medicaid is a safety-net health insurance program for the low-income population. In New York State, over five million low-income individuals enrolled in the Medicaid program in 2012.

Methods

Data

The data used in this study are New York City Medicaid claims prepared by the New York University Health Evaluation and Analytics Lab. The data include Medicaid member demographic information, address history, eligibility, medical services, and diagnostic information. The database consists of Medicaid fee for service claims and managed care encounters; both are comparable in quality.[28]

A priori specifications and hypotheses

We hypothesized that exposure to airplane noise would increase health care utilization, insomnia, mood disorder, anxiety, depression, and cardiovascular disease depending upon the age group.[3,6,8,9,12,13] Specifically, exposure to airplane noise would produce sleep disorders across all age groups,[29] would lead to emotional or behavioral disturbances including substance abuse, mood disorder, depression, and developmental disorders among young adults aged 18 to 45 years who tend to be more at risk of these stress-associated disorders,[30] and would produce or exacerbate cardiovascular disease among older adults aged 45 and over when heart disease begins to increase in prevalence.[31] Noise studies suggest wide-ranging pscychoneuroendocrinological effects (allostatic load) producing hypertension, hyperglycemia, and hypercholesterolemia.[3,6,8,9,12,13,30,31] These biological changes are linked to cardiovascular disease, a correlate of exposure to airplane noise as well as other forms of nighttime noise.[7,10,11,32]

Study Design

We used individual-level data at the member-cohort level for the analysis. We selected samples of Medicaid members residing in each of the two neighborhoods at two points in time. The pre-cohort was defined as Medicaid recipients living in the study neighborhoods between 2009-2011 (pre cohort) and 2013-2016 (post cohort). 64% of the Flushing pre cohort and 63% of the Sunset Park pre cohort were also in the post cohort. We used the difference-in-difference models to analyze the results.

Exposure

To determine exposure, we used data extracted under a FOIA request for flight patterns over Flushing, Queens, New York and from Part 150 Study Technical Advisory Committee Meeting No. 8 documents.[33] These documents were derived from a 2014 study conducted and funded by the Port Authority of NY & NJ (Port Authority) in partnership with the Federal Aviation Administration (FAA). In these documents the Port Authority presents estimated noise exposure in geographies surrounding La Guardia Airport. Exposure is quantified using the Integrated Noise Model in DNL (day-night average sound level) units. We also visually inspected changes in sound related to aircraft flight over sound monitors on the ground in Flushing using Flight Aware, a publicly-available flight tracking website and visited the area.[34] This was done to ensure that the estimates from the Port Authority had face validity.

These geographic regions or corridors were stratified according to intensity of noise exposure over a 24-hour period. We divided census tracts into > 60 DNL, 55-60 DNL, and <55 DNL (Figure 1). We aggregated census tracts and for regions of Flushing, Queens with noise exposure levels of 55 DNL or greater after 2012.[19] These tracts after 2012 are therefore identified as the treatment condition in this quasi-experimental analysis.

Flushing, Queens is a vibrant, predominantly immigrant neighborhood.[24] It is increasingly populated by Asians immigrants, particularly those of Chinese descent. The English proficiency in 2018 was 49%, and the population was 54% Asian and 26% white. While the neighborhood ranked as one of the poorest, the rates of education are higher than average and the rates of crime, obesity, and hypertension are much lower than New York City as a whole.[24]

Sunset Park in Brooklyn, New York was identified as an appropriate control neighborhood as the neighborhood (1) did not experience a change in exposure to aircraft noise after 2012 when the TNNIS climb began frequent use, and (2) is similar to Flushing with respect to the distribution of sociodemographic and economic characteristics.[35,36] Like Flushing, Sunset Park is increasingly populated by those of Chinese descent with 32% of the population identifying as Asian and 23% identifying as white. About 48% of the residents were born outside of the United States and the English proficiency in 2018 was 51%.[25] Sunset Park also has high poverty rates with relatively low rates of crime, obesity, and hypertension, and high levels of education relative to New York City as a whole.[24] Census tracts in Sunset Park were matched to those identified in Flushing based on race, foreign-born status, and age distribution.

Key outcomes

We used International Classification for Disease revision (ICD-9 and ICD-10) codes as well as Clinical Classifications Software (CCS) codes for diagnostic groups to identify the following conditions of interest: insomnia (ICD-9 = 3270, 78052 or ICD-10 = G470), cardiovascular disease (CCS = 109 – 113), alcohol use disorder (CCS=660), substance use disorder (CCS = 661), anxiety (CCS = 651), depression (ICD-9 = 311 or ICD-10 = F33), mood disorder (CCS = 657), and disorders usually diagnosed in infancy, childhood adolescence (CCS = 655), which includes autism, childhood emotional disorder, and separation anxiety.

We linked census tracts of Flushing and Sunset Park to geocoded Medicaid addresses. If a recipient had a Medicaid-registered address within a given census tract, they were assigned to that census tract. Participants were excluded if they had invalid addresses, dual Medicare status, did not have a valid date of birth, or were not officially enrolled in Medicaid during the study period (Table 1). Participant samples were then defined as Medicaid recipients in the period 2009-2011 (pre-implementation period) and 2013-2015 (the TNNIS use period) and who resided within census tracts in Flushing and Sunset Park.

For these identified records, indicator variables were created to identify type of medical claims inpatient, outpatient, and emergency department (ED) visits as well as prescription drugs, both overall and for visits related to substance use and mental health disorders (650-663, 670). We additionally obtained information on the age of the subscriber associated with each record. Because we did not have access to Medicare records, and did not include dual eligible participants due to the high likelihood of pre-existing medical conditions and smaller sample size, our sample does not include adults aged 65 or older. Age in years was defined as the calculated age on January 1, 2009 and January 1, 2013, and stratified into three age cohorts, 5-17, 18-44, 45-64 years.

Statistical analyses

Our focus is on the rate of diagnoses for the hypothesized conditions. We first assess whether there were significant changes in utilization overall between the baseline and TNNIS use periods and whether the observed changes differed by neighborhood (i.e., exposure) after considering other changes over time between these neighborhoods. We use Poisson regression

253 (see equation 1) to model the number of overall and substance use and mental health related
254 inpatient, emergency department and outpatient visits for those months in which participants
255 were enrolled in Medicaid.

256 For our primary analyses, we use logistic regression (see equation 2) to examine the odds
257 of receiving a diagnosis for the hypothesized conditions. Before implementing these regression
258 analyses, we examined trends in socio-demographic characteristics as well as trends in Medicaid
259 enrollment to ensure that no divergent patterns were noted around 2012. Because racial
260 composition varied somewhat between the two neighborhoods (Table 1), we controlled for race
261 in our analyses to ensure that compositional changes by race did not influence the analysis. We
262 also stratified by age so that we could better test our *a priori* hypotheses by condition. For
263 chronic diseases, i.e. cardiovascular disease, we adopted a longer follow-up period 2008-
264 2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in
265 disease manifestation.

266 $$\log\left(E(Y \mid \boldsymbol{x})\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (1)$$

267 $where\ Y = number\ of\ Medicaid\ claims\ for\ condition\ of\ interest$

268 $offset = number\ of\ Medicaid\ enrollment\ months$

269

270 $$\log\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (2)$$

271 $where\ p = \Pr(Y=1)\ is\ the\ probability\ of\ having\ Medicaid\ claim\ for\ condition\ of\ interest$

272 Here, x_1, was the indicator for neighborhood exposure condition (Sunset Park=0 vs
273 Flushing=1); x_2, indicated implementation period (pre-implementation=0 vs TNNIS

implementation=1); and x_3, race/ethnicity group membership (Asian=1, Black=2, Hispanic=3, White=4 [reference], Other=5, Unknown=6).

Patient and Public Involvement

The research question was inspired by the work of a non-profit community organization called Queens Quiet Skies that works to mitigate airplane noise. One of the coauthors of the paper was a member of this organization and obtained the Freedom of Information Act requests for Federal Aviation Administration documents. These documents were used to identify the treatment census tracts and measuring the level of airplane noise exposure.

Results

Participants were generally similar across both groups over the two points in time (Table 1), but health care utilization varied over time by age group and treatment status.

The increased use of the TNNIS climb occurred in 2012.[27] Prior to that date the climb was only used for the US Open or unexpected weather/runway repairs.[27] We were only able to obtain data on TNNIS departures after the New York Port Authority's Fiscal Year 2013 because the Port Authority indicated that the earlier data had been lost. There were roughly 1,278 TNNIS departures/year on average during US Open events in the 2013-2019 period, providing a point of reference. Since 2013, the total annual number of TNNIS climbs ranged from between 9,349 and 29,676, with an average of 18,653/year. The DNL figures (Figure 1) reflect the average noise exposure by census tract across the 2013-2019 period, and may not reflect the actual change in aircraft noise in Flushing, NY in the pre-2012 and post-2012 periods.

Overall medical utilization

Table 2 provides results from regression models assessing period-related changes in medical utilization and diagnoses. The effects of the change in flight patterns on overall utilization were inconsistent across types of utilization and age. Overall, outpatient visits increased slightly in Flushing relative to Sunset Park for those aged 18-44 (rate ratio [RR] = 1.04, 95% CI = 1.04, 1.05). Prescription drug claims also increased by a similar amount for this group (RR = 1.06, 95% CI = 1.06, 1.06). However, outpatient visits and prescription drug use for children in Flushing aged 5-17 (outpatient RR=0.86, 95% CI = 0.85, 0.87; prescription drug claims RR = 0.94, 95% CI = 0.94, 0.95) as well as for older adults 45 – 64 declined (outpatient RR=0.92, 95% CI = 0.92, 0.93; prescription drug claims RR = 0.93, 95% CI = 0.92, 0.93).

While the general pattern for outpatient visits indicates decreased medical utilization in Flushing compared to Sunset Park over time, emergency department visits in Flushing increased in the post TNNIS period among all age groups. For ages 5-17, the RR was 1.31 (95% CI= 1.24, 1.37); for ages 18-44, the RR was 1.45 (95% CI = 1.41, 1.49); and for ages 45-64, the RR was 1.16 (95% CI = 1.11, 1.21). Substance use and mental health-related emergency department visits also increased in Flushing in the post period relative to Sunset Park, with rate ratios ranging between 2.5 to 4.1. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Relative to Sunset Park, inpatient visits in Flushing also show statistically significant increases for overall visits for ages 18-44 (RR=1.05, 95% CI = 1.02, 1.08). However, statistically significant decreases were observed for ages 45-64 (RR=0.93, 95% CI = 0.88, 0.97).

Changes by diagnosis

Relative to Sunset Park, implementation of the TNNIS climb was associated with increases in insomnia diagnoses, particularly for children. For example, the crude prevalence of insomnia for children increased by 57% from 398 per 100,000 in Flushing, compared to a 6% decrease from 477 per 100,000 in Sunset Park. For children in this age group, the odds ratio

320 (OR) for insomnia was 1.64 (95% CI =1.12, 2.39). For older ages, the effect sizes were somewhat less striking (i.e., for the 18-44 age group, the OR was 1.17 [95% CI = 1.09, 1.26], and for ages 45-64 the OR = 1.1 [95% CI = 1.09, 1.28]).

Cardiovascular disease diagnoses increased significantly in Flushing relative to Sunset Park in the post-2012 period. For 18-44-year-olds, the crude prevalence of cardiovascular disease increased in both neighborhoods due to aging of the samples, by 83% from 1,955 per 100,000 in Flushing and by 29% from 1,576 per 100,000 in Sunset Park. The OR for cardiovascular disease diagnoses in Flushing relative to Sunset Park in this age group was 1.45 (95% CI = 1.30, 1.62). For 45-64-year-olds, , the crude prevalence increased by 33% from 9,934 per 100,000 in Flushing and 19% from 9,073 per 100,000 in Sunset Park. For this age group, the OR was 1.15 (95% CI = 1.07, 1.25). Substance use disorder only increased significantly for the 45-64 age group in Flushing relative to Sunset Park (OR =1.24, 95% CI=1.07, 1.44).

Figure 2 shows the monthly prevalence of insomnia and cardiovascular disease diagnoses for the 45-64 age group. Age is measured at the beginning of each period, January 1, 2009 for the pre-period and January 1, 2013 for the post period. The numerator is the number of unique individuals with one or more diagnosis from inpatient, emergency room or outpatient claims and the denominator is the number of Medicaid-enrolled patients. The trends of both conditions increased throughout the study periods, because people are getting older, but Flushing showed increases that were larger in magnitude in the post period relative to Sunset Park.

Results for other conditions were more mixed. Clinical depression diagnoses increased for the two older age groups (ages 18-44 OR = 1.12, 95% CI = 1.02, 1.24; ages 45-64 OR = 1.20, 95% CI = 1.08, 1.33). Broader mood disorder diagnoses, however, only showed statistically significant increases for the 45-65 age group (OR = 1.10, 95% CI = 1.00, 1.20). For 5-17-year-olds, developmental disorder diagnoses significantly decreased (OR=0.80, 95% CI = 0.66, 0.97) in Flushing relative to Sunset Park after the implementation of TNNIS.

Discussion

We find that increases in airplane noise at DNL levels greater than 55 were associated with increases in insomnia, depression, substance abuse, and cardiovascular disease across most age groups. These diagnoses are generally consistent with our *a priori* hypotheses regarding the relationship between exposure to airplane noise and health.[3,6,8,9,12,13,30,31] Specifically, airplane noise may produce disruptions in sleep and psychological stress, thereby producing neuroendocrine disruptions that lead to mental health disorders and cardiovascular disease.

The biological pathways through which airplane noise impacts health have been elucidated.[9-14] Numerous associational studies suggest that airplane noise produces real-world health impacts, and experimental animal models show a wide range of health impacts associated with noise-induced stress as well.[3-9,11-13,15-18,32] Our study adds quasi-experimental evidence in humans to this substantial body of research showing that increasing airplane noise will have detrimental health impacts on communities surrounding airports. The magnitude of our findings is not strictly comparable to those in associational studies because lagged health effects (e.g., the time required for psychological stress to manifest as cardiovascular disease) tend to mute the measured impacts.

Nevertheless, the magnitude of the impact of airplane noise on the health outcomes we observe are generally in line with previous work. For instance, an earlier analysis of associational studies of the health impact of aircraft noise in Flushing, NY estimated that aircraft noise would produce a weighted increase in cardiovascular disease of 14% (RR = 1.14, 95% CI = 1.08, 1.22) and a weighted increase in anxiety of 79% (RR = 1.79, 95% CI = 1.0-3.1).[11,24] We observe an odds ratio for cardiovascular disease among 18-64-year-olds in the range of 1.12 to 1.40. While the studies examine incident cardiovascular disease and we measure both incident and prevalent cardiovascular disease, it is reasonable to assume that the OR we estimate does not greatly overestimate the adjusted RR computed using associational studies.[37]

In the international literature, the self-reported annoyance, health, health-related quality of life, and cardiovascular disease rates for those who live close to airports is significantly lower than for matched individuals living in quieter areas.[38-40] In this literature, these latter findings are particularly true for noise-sensitive individuals.[38,39] This suggests that self-selection by noise may mute previously observed effects in ecological studies, which control for socio-economic status but not always noise sensitivity. One strength of our study is that the change in aircraft noise was exogenous and moving out of a neighborhood requires time and effort.

Our study was subject to a number of limitations. First, the health effects in a predominantly Chinese-American population may not be generalizable to other populations. Chinese-Americans in New York City are unusually healthy.[41] Medicaid data also present unique challenges. Participants can enter and exit the program, for example. If there are more participants exiting the program in one area relative to another, the observed outcomes will also change. We addressed this problem by adjusting for the months a participant was enrolled in Medicaid within a calendar year.

Next, we use DNL as a measure. Frequency of noise exposure may be superior at predicting health outcomes, but frequency data were not available. Finally, it is possible that the change in neighborhood composition over time differed before and after the implementation of year-round TNNIS departures in Flushing relative to Sunset Park. However, we did not observe any trends in the available data that suggested this was the case, and there were no major events in 2012 that clearly serve as an alternative causal factor for either the primary or unexpected findings. Moreover, our findings apply only to the zip codes directly under the DNL zones defined by our analysis.

Cost-effectiveness analyses (based partly on earlier associational data) show that the benefits of noise-mitigation strategies (reduced illness and discomfort) tend to outweigh the costs.[24,42] Given that these earlier studies did not include the full range of health outcomes that we measure here, it is likely that these studies understate the already substantial benefits of aircraft noise mitigation strategies.

Much more comprehensive quasi-experimental and economic analyses are required to determine the extent to which policymakers may wish to act. The costliest options—building airports far from populated areas and providing high speed transit and freeways—can increase the cost of mitigation by billions of dollars.

Research Ethics Approval

This study is approved by the Institutional Review Board at New York University Washington Square under IRB-FY2016-1101.

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411 Disclaimer: The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the New York State Department of Health. Example of analysis performed within this article are only examples. They should not be utilized in real-world analytic products.

Table 1 – Demographics characteristics and outcome prevalence and rates for Flushing, New York and Sunset Park, New York before (earlier than 2012) and after (after 2013) airplane noise increased in Flushing, New York.

Baseline Characteristics	Pre-Period: 2009-2011						Post-Period: 2013-2015					
	Age 5 -17		Age 18-44		Age 45-64		Age 5-17		Age 18-44		Age 45-64	
	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park
Demographics												
Total N	20,120	21,597	57,089	52,016	36,472	18,681	24,552	26,009	76,278	60,774	50,806	24,421
Age (Mean)	11.69	11.12	31.07	29.86	53.44	53.29	11.43	10.71	30.95	30.35	53.99	54.22
Age (STD)	3.94	3.92	8.19	7.54	5.59	5.5	3.94	3.87	7.84	7.25	5.44	5.57
Female (%)	48%	48%	58%	57%	54%	51%	48%	48%	56%	54%	54%	52%
Asian (%)	50%	46%	60%	62%	63%	60%	52%	47%	59%	59%	63%	62%
Black (%)	6%	2%	5%	1%	4%	2%	4%	1%	3%	1%	3%	1%
Hispanic (%)	17%	15%	11%	9%	11%	11%	14%	14%	7%	7%	7%	8%
White (%)	11%	24%	10%	15%	10%	14%	10%	24%	8%	14%	8%	12%
Other (%)	5%	3%	5%	4%	6%	7%	5%	3%	4%	3%	5%	6%
Unknown (%)	12%	11%	10%	8%	6%	5%	14%	12%	20%	16%	13%	11%
Average months on Medicaid per year	9	10	8	8	9	10	9	10	8	8	9	9
Total Medicaid Spending per Person per Year	$1,911	$1,904	$3,818	$3,954	$6,754	$6,076	$1,783	$1,972	$3,398	$3,914	$6,520	$6,115
Prevalence per 100,000												
Insomnia	398	477	4,208	6,096	8,036	9,143	623	450	4,755	5,873	11,034	10,843
Cardiovascular disease*	NA*	NA*	1,955	1,576	9,934	9,073	NA*	NA*	3,575	2,040	13,260	10,786

Alcohol Use Disorder	NA*	NA*	2,114	1,173	2,470	2,184	NA*	NA*	2,264	1,358	2,870	2,199
Substance Use Disorder	NA*	NA*	2,265	1,517	1,799	2,098	NA*	NA*	3,799	2,926	4,250	4,058
Anxiety	NA*	NA*	5,124	4,639	6,279	6,279	NA*	NA*	5,726	5,265	7,537	7,416
Depression	NA*	NA*	3,782	2,874	6,007	5,867	NA*	NA*	3,191	2,272	5,637	4,656
Mood Disorder	NA*	NA*	6,371	4,900	9,399	8,891	NA*	NA*	5,607	4,410	8,375	7,297
Disorders diagnosed young	1,983	1,394	289	212	170	112	2,480	2,219	307	244	163	188
	Visits per 1,000 per year											
Emergency Department	328	216	335	257	288	237	375	188	360	217	332	216
Emergency Department (SM)	13	20	26	21	31	39	20	7	32	12	45	36
Inpatient Stays	70	53	267	319	299	245	60	49	231	300	234	190
Inpatient Stays (SM)	14	7	43	24	45	32	11	5	37	21	37	21
	Outpatient visits per person per year											
Total Outpatient	3.4	4.1	4.1	4.6	6.7	7.3	3.9	5.2	4.5	5.5	7.6	8.2
Outpatient (SM)	0.2	0.2	0.3	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.5	0.4

* We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

Table 2 – Model Results and 95% Confidence Intervals

	Rate Ratios from the Difference in Difference Poisson Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	0.92 (0.83, 1.03)	1.05 (1.02, 1.08)	0.93 (0.88, 0.97)
Emergency Department Visits	1.31 (1.24, 1.37)	1.45 (1.41, 1.49)	1.16 (1.11, 1.21)
Outpatient Visits	0.86 (0.85, 0.87)	1.04 (1.04, 1.05)	0.92 (0.92, 0.93)
Pharmacy Claims	0.94 (0.94, 0.95)	1.06 (1.06, 1.06)	0.93 (0.92, 0.93)
	Rate Ratios from the Difference in Difference Poisson Model Substance Use and Mental Health Related		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	NA*	1.11 (1.01, 1.22)	1.19 (1.04, 1.36)
Emergency Department Visits	4.11 (3.28, 5.16)	2.46 (2.20, 2.76)	1.48 (1.31, 1.67)
Outpatient Visits	1.12 (1.09, 1.16)	0.93 (0.92, 0.95)	0.87 (0.85, 0.89)
	Odds Ratios from the Difference in Difference Logistic Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Insomnia	1.64 (1.12, 2.39)	1.17 (1.09, 1.26)	1.18 (1.09, 1.28)
Cardiovascular Disease**	NA*	1.45 (1.30, 1.62)	1.15 (1.07, 1.25)
Alcohol Use Disorder	NA*	0.97 (0.86, 1.11)	1.16 (0.99, 1.35)
Substance Use Disorder	NA*	0.92 (0.83, 1.03)	1.24 (1.07, 1.44)
Depression	NA*	1.12 (1.02, 1.24)	1.20 (1.08, 1.33)
Anxiety	NA*	1.02 (0.95, 1.10)	1.01 (0.92, 1.11)
Mood Disorder	NA*	1.03 (0.95, 1.10)	1.10 (1.00, 1.20)
Disorders diagnosed young	0.80 (0.66, 0.97)	0.99 (0.72, 1.37)	0.56 (0.31, 1.04)

*These diseases and conditions are rare or difficult to diagnose in children.

**We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

Figure 1 – Intensity of noise exposure over a 24-hour period by census tract. The day night level (DNL) 55 corridor (outer line) is demarcated separately from the DNL 60 corridor (inner line).

Figure 2 – Prevalence of insomnia and cardiovascular disease diagnoses per 100,000 among 45-64 age group

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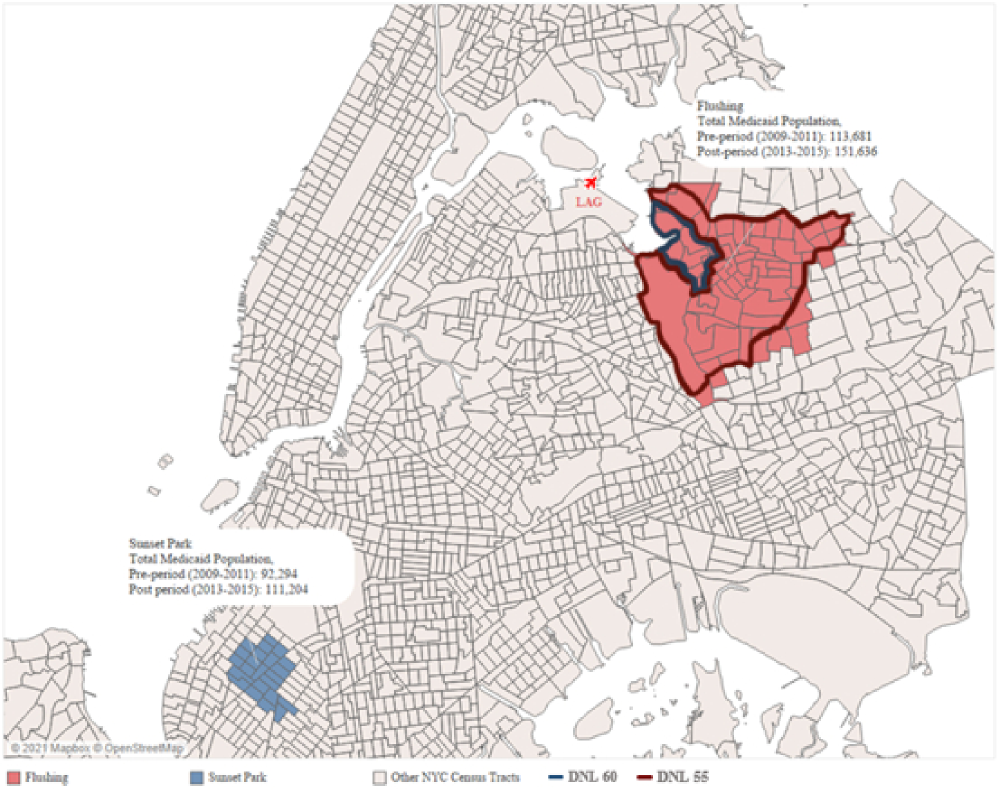

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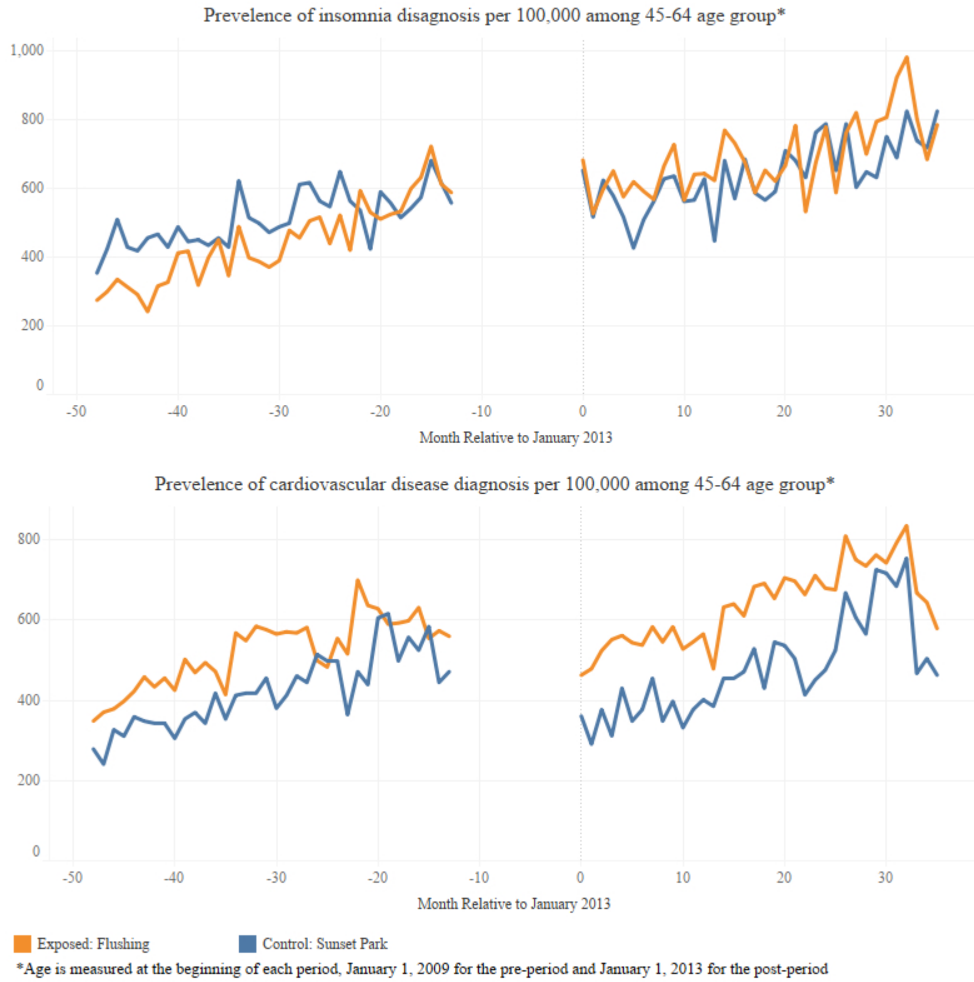

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Title Page

The impact of airplane noise on mental and physical health. A quasi-experimental analysis.

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The impact of airplane noise on mental and physical health: a~~. A~~ quasi-experimental analysis.

Abstract

Objectives. Historically, departures at New York City's La Guardia airport (LGA) flew over a large sports complex within a park. During the US Open tennis games, flights were diverted to fly over a heavily populated foreign-born neighborhood for roughly two weeks out of the year so that the tennis match was not disturbed (the "TNNIS" departure). In 2012, the use of the TNNIS departure became year-round to better optimize flight patterns around the metropolitan area.

Methods. We exploited exogenously-induced spatial and temporal variation in flight patterns ~~in order to~~to examine difference-in-difference effects of this new exposure to aircraft noise on the health of individual residents in the community relative to individuals residing within a demographically similar community that was not impacted. We used individual-level Medicaid records, focusing on conditions associated with noise: sleep disturbance, psychological stress, mental illness, substance use, and cardiovascular disease.

Results. We found that increased ex~~o~~posure to airplane noise was associated with a significant increase in insomnia across all age groups, but particularly in children ages 5-17 (OR = 1.64). Cardiovascular disease increased significantly both among 18-44-year-old (OR = 1.45) and 45-64-year-old Medicaid recipients (OR = 1.15). Substance use and mental health-related emergency department visits also increased. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Conclusion. ~~This study demonstrates~~We find that increased exposure to airplane noise increases diagnosed cardiovascular disease, substance use/mental health emergencies, and insomnia among local residents~~ are the externalities of this decision~~.

66

Strengths and ~~liminations~~limitations

1. ~~Even though w~~We used a quasi-experimental design~~, the study is an ecological study, and therefore we cannot prove causality directly, which is a limitation of the study~~ to study before and after impacts of a flight pattern change in two matched zip code clusters within New York City (a difference-in-difference design).

~~1.~~2. ~~One strength of the study is the use~~We used ~~of~~ a large~~-sealed~~ insurance claims database that allowed us to capture diagnoses~~, as well as providing sufficient stastical power~~for most residents in both impacted and unimpacted zip code clusters.

3. Despite the difference-in-difference design, it is possible that participants self-segregated after the increase in aircraft noise or that other unmeasured factors influenced the observed outcomes.

4. ~~Another limitation of the study is the lack of~~We were unable to compute a dose-response relationship due to the use of ~~aggregrated~~aggregated noise data.

5. ~~A third limitation of the study is the lack of pre-2012 airplane departure data, despite our persistent effort to request.~~ We find that a sudden and dramatic change in aircraft noise increased diagnoses of insomnia, cardiovascular disease, substance abuse, and mental illness.

~~6. One strength of the study is the use of a large-sealed insurance claims database that allowed us to capture diagnoses, as well as providing sufficient stastical power.~~

~~Another strength of the study is the use of a quasi-experiental design and the difference in difference method. Though we cannot prove causality directly, we were able to demonstrate the magnitude of change.~~

What is already known about this subject?

Previous work demonstrated adverse health effect associated with airplane noise, including cardiovascular disease and insomnia using ecological or associational approaches.~~.~~

What are the new findings?

This study exploits exogenous variation in exposure to airplane noise longitudinally in a case and control community in New York City using individual-level Medicaid records. Our difference-in-difference design coupled with more granular ~~and higher quality~~ data suggest that the increased airplane noise was associated with increases in insomnia, substance use/mental health emergencies, and cardiovascular disease may be causal in nature, but additional studies must be done.~~.~~

How might it impact on policy in the foreseeable future?

As air traffic increases, policy makers should consider ~~avoiding residential areas when designing new airports.~~conducting analyses on the health impacts of their policy changes and should strive to build airports further from residential areas.

Authorship Statement

Ms. Scarlett Sijia Wang, Dr. Sherry Glied, Dr. Sharifa Z. Williams and Dr. Peter Meunnig approved the final draft and agreed to be accountable for all aspects of the work. Ms. Scarlett Sijia Wang contributed to study design, data linkage, analysis, interpretation of the data, drafting the methods and results sections. Dr. Sherry Glied contributed to the acquisition of data, study design, analysis, and interpretation of data. Dr. Sharifa Z. Williams contributed to data analysis and interpretation of data. Dr. Peter Muennig contributed to study conception, study design, analysis, interpretation of data and drafting the introduction and discussion sections. Though Mr. Brian Will passed away prior to the submission of the manuscript, he had significant contributions in the study conception, the acquisition of data and sample identification.

Competing Interest

At the time of the study, Mr. Brian Will worked at a non-profit organization called Queens Quiet Skies who are a grass-roots group aiming to address airport noise.

Data Availability

We used individual-level claims data that contain protected Patient Health Information (PHI). Therefore, the data cannot be made unavailable publicly as required by the Health Insurance Portability and Accountability Act (HIPPA).

~~When aircraft enter urban~~ La Guardia's airspace~~, they traditionally approach~~ originally utilized ~~and~~ departures over areas that ~~are~~ were less populated, such as waterways, parks, or areas with warehouses or manufacturing.[1] However, as air traffic increased~~s~~ over time, the airspace used for traditional routes of arrivals and departures ~~has become~~became crowded and conflicted with that of a nearby airport, John F. Kennedy.[2] ~~To~~ As with La Guardia, other airports sometimes ~~handle~~ manage ~~this~~ increases in traffic~~, landings and departures must sometimes be altered to optimize~~ by optimizing flight patterns with less regard for the populations on the ground.[2] Almost invariably, these new flight patterns require routing aircraft over populated areas that were not previously exposed to aircraft noise.

Noise, and aircraft noise in particular, is associated with a number of health problems, particularly sleep disturbances, mental illness, and substance use.[3-8] The sleep disturbances and psychological stress associated with aircraft noise are, in turn, thought to produce a cascade of biological effects that result in premature aging via endocrinologic changes.[9-14]

Noise is thought to produce stress by activating the central nervous system and by interfering with sleep.[3,6,8,15,16] This stress produces predictable changes in biochemical pathways in human and animal studies that accelerate the rate of aging.[14,17,18] This accelerated aging process has been linked to the premature onset of age-related diseases, including cardiovascular disease.[9,19,20]

While the pathways linking poor sleep and psychological stress to premature aging and chronic disease are understood, few studies have experimentally examined interventions that alter noise exposure in human populations.[21] Most of our knowledge about the health impact of aircraft noise in humans is based upon associational studies.[7] These studies suffer from a number of limitations. On one hand, people who live near airports may self-select, such that those who are less sensitive to noise can take advantage of lower home prices on purchases or rentals for homes.[13,19,20] On the other hand, those who live near airports tend to have lower than average income, a major risk factor for premature disease and death.[19,22-24] There is limited evidence based of the impact of aircraft noise on premature aging and health based on experimental or quasi-experimental analysis.[12,13,23,25]

Flight pattern changes afford a unique opportunity for studying the health impact of aircraft noise in humans. In the past decade, flight patterns have shifted, and these shifts have increasingly been accompanied by resident complaints.[26] As they do so, it becomes possible to identify areas that are impacted by new aircraft noise. In general, the point of maximum noise from an aircraft happens immediately after take-off as the aircraft is on full power. This is the ~~case in our study,~~ for the experimental group in our study.

We conducted a longitudinal case/control study of one well-documented flight pattern change in New York City. LaGuardia Airport is one of 3 major airports in the greater New York City area. One of its departure patterns utilizes Flushing Meadows Park, a route known as the "Whitestone Climb." [24] Because it is over greenspace, the Whitestone Climb has little impact on humans living in nearby dwellings. However, this park is also the location of the US Open Tennis match. During games, a seldom-used departure route called the "Flushing Climb" (now called TNNIS) was used so that the tennis games were not disturbed by aircraft noise. The TNNIS climb routes aircraft over densely populated Flushing, Queens, greatly increasing the exposure of residents to noise on the ground.[24]

A Freedom of Information Act (FOIA) request by a local group opposed to airplane noise in Queens demonstrated that flight patterns using the TNNIS climb have increased to year-round use since 2012. Before that time, the use of the TNNIS climb was rare outside of the US Open.[27]

Previous work found that the year-round use of the TNNIS climb was costly, both in terms of money and lives.[24] However, this economic analysis was primarily based on associational data. Using data on flight patterns over Flushing obtained using the FOIA as well as Medicaid utilization data, we conducted a quasi-experimental analysis of the health impacts of the airplane noise associated with this new route. In the United States, Medicaid is a safety-net health insurance program for the low-income population. In New York State, over five million low-income individuals enrolled in the Medicaid program in 2012.

Methods

Data

The data used in this study are New York City Medicaid claims prepared by the New York University Health Evaluation and Analytics Lab. The data include Medicaid member demographic information, address history, eligibility, medical services, and diagnostic information. The database consists of Medicaid fee for service claims and managed care encounters; both are comparable in quality.[28]

A priori specifications and hypotheses

We hypothesized that exposure to airplane noise would increase health care utilization, insomnia, mood disorder, anxiety, depression, and cardiovascular disease depending upon the age group.[3,6,8,9,12,13] Specifically, exposure to airplane noise would produce sleep disorders across all age groups,[29] would lead to emotional or behavioral disturbances including substance abuse, mood disorder, depression, and developmental disorders among young adults aged 18 to ~~<~~ 45 years who tend to be more at risk of these stress-associated disorders,[30] and would produce or exacerbate cardiovascular disease among older adults aged 45 and over when heart disease begins to increase in prevalence.[31] Noise studies suggest wide-ranging pscychoneuroendocrinological effects (allostatic load) producing hypertension, hyperglycemia, and hypercholesterolemia.[3,6,8,9,12,13,30,31] These biological changes are linked to cardiovascular disease, a correlate of exposure to airplane noise as well as other forms of nighttime noise.[7,10,11,32]

Study Design

We used individual-level data at the member-cohort level for the analysis. We selected samples of Medicaid members residing in each of the two neighborhoods at two points in time. The pre-cohort was defined as Medicaid recipients living in the study neighborhoods between 200~~1~~9-2011 (pre cohort) and 2013-2016 (post cohort). 64% of the Flushing pre cohort and 63% of the Sunset Park pre cohort were also in the post cohort. We used the difference-in-difference models to analyze the results.

Exposure

To determine exposure, we used data extracted under a FOIA request for flight patterns over Flushing, Queens, New York and from Part 150 Study Technical Advisory Committee Meeting No. 8 documents.[33] These documents were derived from a 2014 study conducted and funded by the Port Authority of NY & NJ (Port Authority) in partnership with the Federal Aviation Administration (FAA). In these documents the Port Authority presents estimated noise exposure in geographies surrounding La Guardia Airport. Exposure is quantified using the Integrated Noise Model in DNL (day-night average sound level) units. We also visually inspected changes in sound related to aircraft flight over sound monitors on the ground in Flushing using Flight Aware, a publicly-available flight tracking website and visited the area.[34] This was done to ensure that the estimates from the Port Authority had face validity.

These geographic regions or corridors were stratified according to intensity of noise exposure over a 24-hour period. We divided census tracts into > 60 DNL, 55-60 DNL, and <55 DNL (Figure 1). We aggregated census tracts and for regions of Flushing, Queens with noise exposure levels of 55 DNL or greater after 2012.[19] These tracts after 2012 are therefore identified as the treatment condition in this quasi-experimental analysis.

Flushing, Queens is a vibrant, predominantly immigrant neighborhood.[24] It is increasingly populated by Asians immigrants, particularly those of Chinese descent. The English proficiency in 2018 was 49%, and the population was 54% Asian and 26% white. While the neighborhood ranked as one of the poorest, the rates of education are higher than average and the rates of crime, obesity, and hypertension are much lower than New York City as a whole.[24]

Sunset Park in Brooklyn, New York was identified as an appropriate control neighborhood as the neighborhood (1) did not experience a change in exposure to aircraft noise after 2012 when the TNNIS climb began frequent use, and (2) is similar to Flushing with respect to the distribution of sociodemographic and economic characteristics.[35,36] Like Flushing, Sunset Park is increasingly populated by those of Chinese descent with 32% of the population identifying as Asian and 23% identifying as white. About 48% of the residents were born outside of the United States and the English proficiency in 2018 was 51%.[25] Sunset Park also has high poverty rates with relatively low rates of crime, obesity, and hypertension, and high levels of education relative to New York City as a whole.[24] Census tracts in Sunset Park were matched to those identified in Flushing based on race, foreign-born status, and age distribution.

Key outcomes

We used International Classification for Disease revision (ICD-9 and ICD-10) codes as well as Clinical Classifications Software (CCS) codes for diagnostic groups to identify the following conditions of interest: insomnia (ICD-9 = 3270, 78052 or ICD-10 = G470), cardiovascular disease (CCS = 109 – 113), alcohol use disorder (CCS=660), substance use disorder (CCS = 661), anxiety (CCS = 651), depression (ICD-9 = 311 or ICD-10 = F33), mood disorder (CCS = 657), and disorders usually diagnosed in infancy, childhood adolescence (CCS = 655), which includes autism, childhood emotional disorder, and separation anxiety.

We linked census tracts of Flushing and Sunset Park to geocoded Medicaid addresses. If a recipient had a Medicaid-registered address within a given census tract, they were assigned to that census tract. Participants were excluded if they had invalid addresses, dual Medicare status, did not have a valid date of birth, or were not officially enrolled in Medicaid during the study period (Table 1). Participant samples were then defined as Medicaid recipients in the period 2009-2011 (pre-implementation period) and 2013-2015 (the TNNIS use period) and who resided within census tracts in Flushing and Sunset Park.

For these identified records, indicator variables were created to identify type of medical claims inpatient, outpatient, and emergency department (ED) visits as well as prescription drugs, both overall and for visits related to substance use and mental health disorders (650-663, 670). We additionally obtained information on the age of the subscriber associated with each record. Because we did not have access to Medicare records, and did not include dual eligible participants due to the high likelihood of pre-existing medical conditions and smaller sample size, our sample does not include adults aged 65 or older. Age in years was defined as the calculated age on January 1, 2009 and January 1, 2013, and stratified into three age cohorts, 5-17, 18-44, 45-64 years.

Statistical analyses

Our focus is on the rate of diagnoses for the hypothesized conditions. We first assess whether there were significant changes in utilization overall between the baseline and TNNIS use periods and whether the observed changes differed by neighborhood (i.e., exposure) after considering other changes over time between these neighborhoods. We use Poisson regression (see equation 1) to model the number of overall and substance use and mental health related inpatient, emergency department and outpatient visits for those months in which participants were enrolled in Medicaid.

For our primary analyses, we use logistic regression (see equation 2) to examine the odds of receiving a diagnosis for the hypothesized conditions. Before implementing these regression analyses, we examined trends in socio-demographic characteristics as well as trends in Medicaid enrollment to ensure that no divergent patterns were noted around 2012. Because racial composition varied somewhat between the two neighborhoods (Table 1), we controlled for race in our analyses to ensure that compositional changes by race did not influence the analysis. We also stratified by age so that we could better test our *a priori* hypotheses by condition. For chronic diseases, i.e. cardiovascular disease, we adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation.

$$\log\left(E(Y \mid \boldsymbol{x})\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (1)$$

$$where\ Y = number\ of\ Medicaid\ claims\ for\ condition\ of\ interest$$

$$offset = number\ of\ Medicaid\ enrollment\ months$$

$$\log\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (2)$$

$where\ p = \Pr(Y = 1)\ is\ the\ probability\ of\ having\ Medicaid\ claim\ for\ condition\ of\ interest$

Here, x_1, was the indicator for neighborhood exposure condition (Sunset Park=0 vs Flushing=1); x_2, indicated implementation period (pre-implementation=0 vs TNNIS implementation=1); and x_3, race/ethnicity group membership (Asian=1, Black=2, Hispanic=3, White=4 [reference], Other=5, Unknown=6).

Patient and Public Involvement

The research question was inspired by the work of a non-profit community organization called Queens Quiet Skies that works to mitigate airplane noise. One of the coauthors of the paper was a member of this organization and obtained the Freedom of Information Act requests for Federal Aviation Administration documents. These documents were used to identify the treatment census tracts and measuring the level of airplane noise exposure.

Results

Participants were generally similar across both groups over the two points in time (Table 1), but health care utilization varied over time by age group and treatment status.

The increased use of the TNNIS climb occurred in 2012.[27] Prior to that date the climb was only used for the US Open or unexpected weather/runway repairs.[27] We were only able to obtain data on TNNIS departures after the New York Port Authority's Fiscal Year 2013 because the Port Authority indicated that the earlier data had been lost. There were roughly 1,278 TNNIS departures/year on average during US Open events in the 2013-2019 period, providing a point of reference. Since 2013, the total annual number of TNNIS climbs ranged from between 9,349 and 29,676, with an average of 18,653/year. The DNL figures (Figure 1) reflect the average noise exposure by census tract across the 2013-2019 period, and may not reflect the actual change in aircraft noise in Flushing, NY in the pre-2012 and post-2012 periods.

Overall medical utilization

Table 2 provides results from regression models assessing period-related changes in medical utilization and diagnoses. The effects of the change in flight patterns on overall utilization were inconsistent across types of utilization and age. Overall, outpatient visits increased slightly in Flushing relative to Sunset Park for those aged 18-44 (rate ratio [RR] = 1.04, 95% CI = 1.04, 1.05). Prescription drug claims also increased by a similar amount for this group (RR = 1.06, 95% CI = 1.06, 1.06). However, outpatient visits and prescription drug use for children in Flushing aged 5-17 (outpatient RR=0.86, 95% CI = 0.85, 0.87; prescription drug claims RR = 0.94, 95% CI = 0.94, 0.95) as well as for older adults 45 – 64 declined (outpatient RR=0.92, 95% CI = 0.92, 0.93; prescription drug claims RR = 0.93, 95% CI = 0.92, 0.93).

While the general pattern for outpatient visits indicates decreased medical utilization in Flushing compared to Sunset Park over time, emergency department visits in Flushing increased in the post TNNIS period among all age groups. For ages 5-17, the RR was 1.31 (95% CI= 1.24, 1.37); for ages 18-44, the RR was 1.45 (95% CI = 1.41, 1.49); and for ages 45-64, the RR was 1.16 (95% CI = 1.11, 1.21). Substance use and mental health-related emergency department visits also increased in Flushing in the post period relative to Sunset Park, with rate ratios ranging between 2.5 to 4.1. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Relative to Sunset Park, inpatient visits in Flushing also show statistically significant increases for overall visits for ages 18-44 (RR=1.05, 95% CI = 1.02, 1.08). However, statistically significant decreases were observed for ages 45-64 (RR=0.93, 95% CI = 0.88, 0.97).

Changes by diagnosis

Relative to Sunset Park, implementation of the TNNIS climb was associated with increases in insomnia diagnoses, particularly for children. For example, the crude prevalence of insomnia for children increased by 57% from 398 per 100,000 in Flushing, compared to a 6% decrease from 477 per 100,000 in Sunset Park. For children in this age group, the odds ratio (OR) for insomnia was 1.64 (95% CI =1.12, 2.39). For older ages, the effect sizes were somewhat less striking (i.e., for the 18-44 age group, the OR was 1.17 [95% CI = 1.09, 1.26], and for ages 45-64 the OR = 1.1 [95% CI = 1.09, 1.28]).

Cardiovascular disease diagnoses increased significantly in Flushing relative to Sunset Park in the post-2012 period. For 18-44-year-olds, the crude prevalence of cardiovascular disease increased in both neighborhoods due to aging of the samples, by 83% from 1,955 per 100,000 in Flushing and by 29% from 1,576 per 100,000 in Sunset Park. The OR for cardiovascular disease diagnoses in Flushing relative to Sunset Park in this age group was 1.45 (95% CI = 1.30, 1.62). For 45-64-year-olds, , the crude prevalence increased by 33% from 9,934 per 100,000 in Flushing and 19% from 9,073 per 100,000 in Sunset Park. For this age group, the OR was 1.15 (95% CI = 1.07, 1.25). Substance use disorder only increased significantly for the 45-64 age group in Flushing relative to Sunset Park (OR =1.24, 95% CI=1.07, 1.44).

Figure 2 shows the monthly prevalence of insomnia and cardiovascular disease diagnoses for the 45-64 age group. Age is measured at the beginning of each period, January 1, 2009 for the pre-period and January 1, 2013 for the post period. The numerator is the number of unique individuals with one or more diagnosis from inpatient, emergency room or outpatient claims and the denominator is the number of Medicaid-enrolled patients. The trends of both conditions increased throughout the study periods, because people are getting older, but Flushing showed increases that were larger in magnitude in the post period relative to Sunset Park.

Results for other conditions were more mixed. Clinical depression diagnoses increased for the two older age groups (ages 18-44 OR = 1.12, 95% CI = 1.02, 1.24; ages 45-64 OR = 1.20, 95% CI = 1.08, 1.33). Broader mood disorder diagnoses, however, only showed statistically significant increases for the 45-65 age group (OR = 1.10, 95% CI = 1.00, 1.20). For 5-17-year-olds, developmental disorder diagnoses significantly decreased (OR=0.80, 95% CI = 0.66, 0.97) in Flushing relative to Sunset Park after the implementation of TNNIS.

Discussion

We find that increases in airplane noise at DNL levels greater than 55 were associated with increases in insomnia, depression, substance abuse, and cardiovascular disease across most age groups. These diagnoses are generally consistent with our *a priori* hypotheses regarding the relationship between exposure to airplane noise and health.[3,6,8,9,12,13,30,31] Specifically, airplane noise may produce disruptions in sleep and psychological stress, thereby producing neuroendocrine disruptions that lead to mental health disorders and cardiovascular disease.

~~Our study was subject to a number of limitations. First, the health effects in a predominantly Chinese-American population may not be generalizable to other populations. Chinese-Americans in New York City are unusually healthy.[37] Medicaid data also present unique challenges. Participants can enter and exit the program, for example. If there are more participants exiting the program in one area relative to another, the observed outcomes will also change. We addressed this problem by adjusting for the months a participant was enrolled in Medicaid within a calendar year, but noise may nevertheless be introduced in the analysis. Finally, it is possible that the change in neighborhood composition over time differed before and after the implementation of year-round TNNIS departures in Flushing relative to Sunset Park.~~

~~However, we did not observe any trends in the available data that suggested this was the case, and there were no major events in 2012 that clearly serve as an alternative causal factor for either the primary or unexpected findings.~~

The biological pathways through which airplane noise impacts health have been elucidated.[9-14] Numerous associational studies suggest that airplane noise produces real-world health impacts, and experimental animal models show a wide range of health impacts associated with noise-induced stress as well.[3-9,11-13,15-18,32] Our study adds quasi-experimental evidence in humans to this substantial body of research showing that increasing airplane noise will have detrimental health impacts on communities surrounding airports. The magnitude of our findings is not strictly comparable to those in associational studies because lagged health effects (e.g., the time required for psychological stress to manifest as cardiovascular disease) tend to mute the measured impacts.

Nevertheless, the magnitude of the impact of airplane noise on the health outcomes we observe are generally in line with ~~associational studies~~previous work. For instance, an earlier analysis of associational studies of the health impact of aircraft noise in Flushing, NY estimated that aircraft noise would produce a weighted increase in cardiovascular disease of 14% (RR = 1.14, 95% CI = 1.08, 1.22) and a weighted increase in anxiety of 79% (RR = 1.79, 95% CI = 1.0-3.1).[11,24] We observe an odds ratio for cardiovascular disease among 18-64-year-olds in the range of 1.12 to 1.40. While the studies examine incident cardiovascular disease and we measure both incident and prevalent cardiovascular disease, it is reasonable to assume that the OR we estimate does not greatly overestimate the adjusted RR computed using associational studies.[37]

In the international literature, the self-reported annoyance, health, health-related quality of life, and cardiovascular disease rates for those who live close to airports is significantly lower than for matched individuals living in quieter areas.[38-40] In this literature, these latter findings are particularly true for noise-sensitive individuals.[38,39] This suggests that self-selection by noise may mute previously observed effects in ecological studies, which control for socio-economic status but not always noise sensitivity. One strength of our study is that the change in aircraft noise was exogenous and moving out of a neighborhood requires time and effort.

Our study was subject to a number of limitations. First, the health effects in a predominantly Chinese-American population may not be generalizable to other populations. Chinese-Americans in New York City are unusually healthy.[41] Medicaid data also present unique challenges. Participants can enter and exit the program, for example. If there are more participants exiting the program in one area relative to another, the observed outcomes will also change. We addressed this problem by adjusting for the months a participant was enrolled in Medicaid within a calendar year.

Next, we use DNL as a measure. Frequency of noise exposure may be superior at predicting health outcomes, but frequency data were not available. Finally, it is possible that the change in neighborhood composition over time differed before and after the implementation of year-round TNNIS departures in Flushing relative to Sunset Park. However, we did not observe any trends in the available data that suggested this was the case, and there were no major events in 2012 that clearly serve as an alternative causal factor for either the primary or unexpected findings. Moreover, our findings apply only to the zip codes directly under the DNL zones defined by our analysis.

Cost-effectiveness analyses (based partly on earlier associational data) show that the benefits of noise-mitigation strategies (reduced illness and discomfort) tend to outweigh the costs.[24,42] Given that these earlier studies did not include the full range of health outcomes that we measure here, it is likely that these studies understate the already substantial benefits of aircraft noise mitigation strategies.

Much more comprehensive quasi-experimental and economic analyses are required to determine the extent to which policymakers may wish to act. The costliest options—building airports far from populated areas and providing high speed transit and freeways—can increase the cost of mitigation by billions of dollars.

Research Ethics Approval

This study is approved by the Institutional Review ~~Borad~~Board at New York University Washington Square under IRB-FY2016-1101.

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Disclaimer: The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the New York State Department of Health. Example of analysis performed within this article are only examples. They should not be utilized in real-world analytic products.

Table 1 – Demographics characteristics and outcome prevalence and rates for Flushing, New York and Sunset Park, New York before (earlier than 2012) and after (after 2013) airplane noise increased in Flushing, New York.

Baseline Characteristics	Pre-Period: 2009-2011						Post-Period: 2013-2015					
	Age 5 -17		Age 18-44		Age 45-64		Age 5-17		Age 18-44		Age 45-64	
	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park
Demographics												
Total N	20,120	21,597	57,089	52,016	36,472	18,681	24,552	26,009	76,278	60,774	50,806	24,421
Age (Mean)	11.69	11.12	31.07	29.86	53.44	53.29	11.43	10.71	30.95	30.35	53.99	54.22
Age (STD)	3.94	3.92	8.19	7.54	5.59	5.5	3.94	3.87	7.84	7.25	5.44	5.57
Female (%)	48%	48%	58%	57%	54%	51%	48%	48%	56%	54%	54%	52%
Asian (%)	50%	46%	60%	62%	63%	60%	52%	47%	59%	59%	63%	62%
Black (%)	6%	2%	5%	1%	4%	2%	4%	1%	3%	1%	3%	1%
Hispanic (%)	17%	15%	11%	9%	11%	11%	14%	14%	7%	7%	7%	8%
White (%)	11%	24%	10%	15%	10%	14%	10%	24%	8%	14%	8%	12%
Other (%)	5%	3%	5%	4%	6%	7%	5%	3%	4%	3%	5%	6%
Unknown (%)	12%	11%	10%	8%	6%	5%	14%	12%	20%	16%	13%	11%
Average months on Medicaid per year	9	10	8	8	9	10	9	10	8	8	9	9
Total Medicaid Spending per Person per Year	$1,911	$1,904	$3,818	$3,954	$6,754	$6,076	$1,783	$1,972	$3,398	$3,914	$6,520	$6,115
Prevalence per 100,000												
Insomnia	398	477	4,208	6,096	8,036	9,143	623	450	4,755	5,873	11,034	10,843
Cardiovascular disease*	NA*	NA*	1,955	1,576	9,934	9,073	NA*	NA*	3,575	2,040	13,260	10,786

Alcohol Use Disorder	NA*	NA*	2,114	1,173	2,470	2,184	NA*	NA*	2,264	1,358	2,870	2,199
Substance Use Disorder	NA*	NA*	2,265	1,517	1,799	2,098	NA*	NA*	3,799	2,926	4,250	4,058
Anxiety	NA*	NA*	5,124	4,639	6,279	6,279	NA*	NA*	5,726	5,265	7,537	7,416
Depression	NA*	NA*	3,782	2,874	6,007	5,867	NA*	NA*	3,191	2,272	5,637	4,656
Mood Disorder	NA*	NA*	6,371	4,900	9,399	8,891	NA*	NA*	5,607	4,410	8,375	7,297
Disorders diagnosed young	1,983	1,394	289	212	170	112	2,480	2,219	307	244	163	188
	Visits per 1,000 per year											
Emergency Department	328	216	335	257	288	237	375	188	360	217	332	216
Emergency Department (SM)	13	20	26	21	31	39	20	7	32	12	45	36
Inpatient Stays	70	53	267	319	299	245	60	49	231	300	234	190
Inpatient Stays (SM)	14	7	43	24	45	32	11	5	37	21	37	21
	Outpatient visits per person per year											
Total Outpatient	3.4	4.1	4.1	4.6	6.7	7.3	3.9	5.2	4.5	5.5	7.6	8.2
Outpatient (SM)	0.2	0.2	0.3	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.5	0.4

* We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

Table 2 – Model Results and 95% Confidence Intervals

	Rate Ratios from the Difference in Difference Poisson Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	0.92 (0.83, 1.03)	1.05 (1.02, 1.08)	0.93 (0.88, 0.97)
Emergency Department Visits	1.31 (1.24, 1.37)	1.45 (1.41, 1.49)	1.16 (1.11, 1.21)
Outpatient Visits	0.86 (0.85, 0.87)	1.04 (1.04, 1.05)	0.92 (0.92, 0.93)
Pharmacy Claims	0.94 (0.94, 0.95)	1.06 (1.06, 1.06)	0.93 (0.92, 0.93)
	Rate Ratios from the Difference in Difference Poisson Model Substance Use and Mental Health Related		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	NA*	1.11 (1.01, 1.22)	1.19 (1.04, 1.36)
Emergency Department Visits	4.11 (3.28, 5.16)	2.46 (2.20, 2.76)	1.48 (1.31, 1.67)
Outpatient Visits	1.12 (1.09, 1.16)	0.93 (0.92, 0.95)	0.87 (0.85, 0.89)
	Odds Ratios from the Difference in Difference Logistic Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Insomnia	1.64 (1.12, 2.39)	1.17 (1.09, 1.26)	1.18 (1.09, 1.28)
Cardiovascular Disease**	NA*	1.45 (1.30, 1.62)	1.15 (1.07, 1.25)
Alcohol Use Disorder	NA*	0.97 (0.86, 1.11)	1.16 (0.99, 1.35)
Substance Use Disorder	NA*	0.92 (0.83, 1.03)	1.24 (1.07, 1.44)
Depression	NA*	1.12 (1.02, 1.24)	1.20 (1.08, 1.33)
Anxiety	NA*	1.02 (0.95, 1.10)	1.01 (0.92, 1.11)
Mood Disorder	NA*	1.03 (0.95, 1.10)	1.10 (1.00, 1.20)
Disorders diagnosed young	0.80 (0.66, 0.97)	0.99 (0.72, 1.37)	0.56 (0.31, 1.04)

*These diseases and conditions are rare or difficult to diagnose in children.

**We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

Figure 1 – Intensity of noise exposure over a 24-hour period by census tract. The day night level (DNL) 55 corridor (outer line) is demarcated separately from the DNL 60 corridor (inner line).

Figure 2 – Prevalence of insomnia and cardiovascular disease diagnoses per 100,000 among 45-64 age group

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2-3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4-6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4
Bias	9	Describe any efforts to address potential sources of bias	7, 11
Study size	10	Explain how the study size was arrived at	8, 14-15
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	7-8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	8, 14-15
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	8,14-15
Outcome data	15*	Report numbers of outcome events or summary measures over time	8-11, 14

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8-11, 14-19
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	11-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Supplemental material, acknowledgements

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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The impact of airplane noise on mental and physical health. A quasi-experimental analysis.

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Title Page

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The impact of airplane noise on mental and physical health: a quasi-experimental analysis.

Abstract

Objectives. Historically, departures at New York City's La Guardia airport (LGA) flew over a large sports complex within a park. During the US Open tennis games, flights were diverted to fly over a heavily populated foreign-born neighborhood for roughly two weeks out of the year so that the tennis match was not disturbed (the "TNNIS" departure). In 2012, the use of the TNNIS departure became year-round to better optimize flight patterns around the metropolitan area.

Methods. We exploited exogenously-induced spatial and temporal variation in flight patterns to examine difference-in-difference effects of this new exposure to aircraft noise on the health of individual residents in the community relative to individuals residing within a demographically similar community that was not impacted. We used individual-level Medicaid records, focusing on conditions associated with noise: sleep disturbance, psychological stress, mental illness, substance use, and cardiovascular disease.

Results. We found that increased exposure to airplane noise was associated with a significant increase in insomnia across all age groups, but particularly in children ages 5-17 (OR = 1.64). Cardiovascular disease increased significantly both among 18-44-year-old (OR = 1.45) and 45-64-year-old Medicaid recipients (OR = 1.15). Substance use and mental health-related emergency department visits also increased. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

Conclusion. We find that increased exposure to airplane noise was associated with an increase in diagnosis of cardiovascular disease, substance use/mental health emergencies, and insomnia among local residents.

Strengths and limitations

1. We used a quasi-experimental design to study before and after impacts of a flight pattern change in two matched zip code clusters within New York City (a difference-in-difference design).
2. We used a large health insurance claims database that allowed us to capture diagnoses for most residents in both impacted and unimpacted zip code clusters.
3. Despite the difference-in-difference design, it is possible that participants self-segregated after the increase in aircraft noise or that other unmeasured factors influenced the observed outcomes.
4. We were unable to compute a dose-response relationship due to the use of aggregated noise data.
5. We find that a sudden and dramatic change in aircraft noise was associated with increased diagnoses of insomnia, cardiovascular disease, substance abuse, and mental illness.

84 La Guardia's airspace originally utilized departures over areas that were less populated, such as waterways, parks, or areas with warehouses or manufacturing.[1] However, as air traffic increased over time, the airspace used for traditional routes of arrivals and departures became crowded and conflicted with that of a nearby airport, John F. Kennedy.[2] As with La Guardia, other airports sometimes manage increases in traffic by optimizing flight patterns with less regard for the populations on the ground.[2] Almost invariably, these new flight patterns require routing aircraft over populated areas that were not previously exposed to aircraft noise.

91 Noise, and aircraft noise in particular, is associated with a number of health problems, particularly sleep disturbances, mental illness, and substance use.[3-8] The sleep disturbances and psychological stress associated with aircraft noise are, in turn, thought to produce a cascade of biological effects that result in premature aging via endocrinologic changes.[9-14]

95 Noise is thought to produce stress by activating the central nervous system and by interfering with sleep.[3,6,8,15,16] This stress produces predictable changes in biochemical pathways in human and animal studies that accelerate the rate of aging.[14,17,18] This accelerated aging process has been linked to the premature onset of age-related diseases, including cardiovascular disease.[9,19,20]

100 While the pathways linking poor sleep and psychological stress to premature aging and chronic disease are understood, few studies have experimentally examined interventions that alter noise exposure in human populations.[21] Most of our knowledge about the health impact of aircraft noise in humans is based upon associational studies.[7] These studies suffer from a number of limitations. On one hand, people who live near airports may self-select, such that those who are less sensitive to noise can take advantage of lower home prices on purchases or rentals for homes.[13,19,20] On the other hand, those who live near airports tend to have lower than average

income, a major risk factor for premature disease and death.[19,22-24] There is limited evidence based of the impact of aircraft noise on premature aging and health based on experimental or quasi-experimental analysis.[12,13,23,25]

Flight pattern changes afford a unique opportunity for studying the health impact of aircraft noise in humans. In the past decade, flight patterns have shifted, and these shifts have increasingly been accompanied by resident complaints.[26] As they do so, it becomes possible to identify areas that are impacted by new aircraft noise. In general, the point of maximum noise from an aircraft happens immediately after take-off as the aircraft is on full power. This is the for the experimental group in our study.

We conducted a longitudinal case/control study of one well-documented flight pattern change in New York City. LaGuardia Airport is one of 3 major airports in the greater New York City area. One of its departure patterns utilizes Flushing Meadows Park, a route known as the "Whitestone Climb." [24] Because it is over greenspace, the Whitestone Climb has little impact on humans living in nearby dwellings. However, this park is also the location of the US Open Tennis match. During games, a seldom-used departure route called the "Flushing Climb" (now called TNNIS) was used so that the tennis games were not disturbed by aircraft noise. The TNNIS climb routes aircraft over densely populated Flushing, Queens, greatly increasing the exposure of residents to noise on the ground.[24]

A Freedom of Information Act (FOIA) request by a local group opposed to airplane noise in Queens demonstrated that flight patterns using the TNNIS climb have increased to year-round use since 2012. Before that time, the use of the TNNIS climb was rare outside of the US Open.[27]

Previous work found that the year-round use of the TNNIS climb was costly, both in terms of money and lives.[24] However, this economic analysis was primarily based on associational data. Using data on flight patterns over Flushing obtained using the FOIA as well as Medicaid utilization data, we conducted a quasi-experimental analysis of the health impacts of the airplane noise associated with this new route. In the United States, Medicaid is a safety-net health insurance program for the low-income population. In New York State, over five million low-income individuals enrolled in the Medicaid program in 2012.

Methods

Data

The data used in this study are New York City Medicaid claims prepared by the New York University Health Evaluation and Analytics Lab. The data include Medicaid member demographic information, address history, eligibility, medical services, and diagnostic information. The database consists of Medicaid fee for service claims and managed care encounters; both are comparable in quality.[28]

A priori specifications and hypotheses

We hypothesized that exposure to airplane noise would increase health care utilization, insomnia, mood disorder, anxiety, depression, and cardiovascular disease depending upon the age group.[3,6,8,9,12,13] Specifically, exposure to airplane noise would produce sleep disorders across all age groups,[29] would lead to emotional or behavioral disturbances including substance abuse, mood disorder, depression, and developmental disorders among young adults aged 18 to 45 years who tend to be more at risk of these stress-associated disorders,[30] and would produce or exacerbate cardiovascular disease among older adults aged 45 and over when heart disease begins to increase in prevalence.[31] Noise studies suggest wide-ranging pscychoneuroendocrinological effects (allostatic load) producing hypertension, hyperglycemia, and hypercholesterolemia.[3,6,8,9,12,13,30,31] These biological changes are linked to cardiovascular disease, a correlate of exposure to airplane noise as well as other forms of nighttime noise.[7,10,11,32]

Study Design

We used individual-level data at the member-cohort level for the analysis. We selected samples of Medicaid members residing in each of the two neighborhoods at two points in time. The pre-cohort was defined as Medicaid recipients living in the study neighborhoods between 2009-2011 (pre cohort) and 2013-2016 (post cohort). 64% of the Flushing pre cohort and 63% of the Sunset Park pre cohort were also in the post cohort. We used the difference-in-difference models to analyze the results.

Exposure

To determine exposure, we used data extracted under a FOIA request for flight patterns over Flushing, Queens, New York and from Part 150 Study Technical Advisory Committee Meeting No. 8 documents.[33] These documents were derived from a 2014 study conducted and funded by the Port Authority of NY & NJ (Port Authority) in partnership with the Federal Aviation Administration (FAA). In these documents the Port Authority presents estimated noise exposure in geographies surrounding La Guardia Airport. Exposure is quantified using the Integrated Noise Model in DNL (day-night average sound level) units. We also visually inspected changes in sound related to aircraft flight over sound monitors on the ground in Flushing using Flight Aware, a publicly-available flight tracking website and visited the area.[34] This was done to ensure that the estimates from the Port Authority had face validity.

These geographic regions or corridors were stratified according to intensity of noise exposure over a 24-hour period. We divided census tracts into > 60 DNL, 55-60 DNL, and <55 DNL (Figure 1). We aggregated census tracts and for regions of Flushing, Queens with noise exposure levels of 55 DNL or greater after 2012.[19] These tracts after 2012 are therefore identified as the treatment condition in this quasi-experimental analysis.

Figure 1 – Intensity of noise exposure over a 24-hour period by census tract. The day night level (DNL) 55 corridor (outer line) is demarcated separately from the DNL 60 corridor (inner line).

[insert figure 1 here]

Flushing, Queens is a vibrant, predominantly immigrant neighborhood.[24] It is increasingly populated by Asians immigrants, particularly those of Chinese descent. The English proficiency in 2018 was 49%, and the population was 54% Asian and 26% white. While the neighborhood ranked as one of the poorest, the rates of education are higher than average and the rates of crime, obesity, and hypertension are much lower than New York City as a whole.[24]

Sunset Park in Brooklyn, New York was identified as an appropriate control neighborhood as the neighborhood (1) did not experience a change in exposure to aircraft noise after 2012 when the TNNIS climb began frequent use, and (2) is similar to Flushing with respect to the distribution of sociodemographic and economic characteristics.[35,36] Like Flushing, Sunset Park is increasingly populated by those of Chinese descent with 32% of the population identifying as Asian and 23% identifying as white. About 48% of the residents were born outside of the United States and the English proficiency in 2018 was 51%.[25] Sunset Park also has high poverty rates with relatively low rates of crime, obesity, and hypertension, and high levels of education relative to New York City as a whole.[24] Census tracts in Sunset Park were matched to those identified in Flushing based on race, foreign-born status, and age distribution.

Key outcomes

We used International Classification for Disease revision (ICD-9 and ICD-10) codes as well as Clinical Classifications Software (CCS) codes for diagnostic groups to identify the following conditions of interest: insomnia (ICD-9 = 3270, 78052 or ICD-10 = G470), cardiovascular disease (CCS = 109 – 113), alcohol use disorder (CCS=660), substance use disorder (CCS = 661), anxiety (CCS = 651), depression (ICD-9 = 311 or ICD-10 = F33), mood disorder (CCS = 657), and disorders usually diagnosed in infancy, childhood adolescence (CCS = 655), which includes autism, childhood emotional disorder, and separation anxiety.

We linked census tracts of Flushing and Sunset Park to geocoded Medicaid addresses. If a recipient had a Medicaid-registered address within a given census tract, they were assigned to that census tract. Participants were excluded if they had invalid addresses, dual Medicare status, did not have a valid date of birth, or were not officially enrolled in Medicaid during the study period (Table 1). Participant samples were then defined as Medicaid recipients in the period 2009-2011 (pre-implementation period) and 2013-2015 (the TNNIS use period) and who resided within census tracts in Flushing and Sunset Park.

Table 1 – Demographics characteristics and outcome prevalence and rates for Flushing, New York and Sunset Park, New York before (earlier than 2012) and after (after 2013) airplane noise increased in Flushing, New York.

Baseline Characteristics	Pre-Period: 2009-2011						Post-Period: 2013-2015					
	Age 5 -17		Age 18-44		Age 45-64		Age 5-17		Age 18-44		Age 45-64	
	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park	Flushing	Sunset Park
Demographics												
Total N	20,120	21,597	57,089	52,016	36,472	18,681	24,552	26,009	76,278	60,774	50,806	24,421
Age (Mean)	11.69	11.12	31.07	29.86	53.44	53.29	11.43	10.71	30.95	30.35	53.99	54.22
Age (STD)	3.94	3.92	8.19	7.54	5.59	5.5	3.94	3.87	7.84	7.25	5.44	5.57
Female (%)	48%	48%	58%	57%	54%	51%	48%	48%	56%	54%	54%	52%
Asian (%)	50%	46%	60%	62%	63%	60%	52%	47%	59%	59%	63%	62%
Black (%)	6%	2%	5%	1%	4%	2%	4%	1%	3%	1%	3%	1%
Hispanic (%)	17%	15%	11%	9%	11%	11%	14%	14%	7%	7%	7%	8%
White (%)	11%	24%	10%	15%	10%	14%	10%	24%	8%	14%	8%	12%
Other (%)	5%	3%	5%	4%	6%	7%	5%	3%	4%	3%	5%	6%
Unknown (%)	12%	11%	10%	8%	6%	5%	14%	12%	20%	16%	13%	11%
Average months on Medicaid per year	9	10	8	8	9	10	9	10	8	8	9	9
Total Medicaid Spending per Person per Year	$1,911	$1,904	$3,818	$3,954	$6,754	$6,076	$1,783	$1,972	$3,398	$3,914	$6,520	$6,115
Prevalence per 100,000												
Insomnia	398	477	4,208	6,096	8,036	9,143	623	450	4,755	5,873	11,034	10,843
Cardiovascular disease*	NA*	NA*	1,955	1,576	9,934	9,073	NA*	NA*	3,575	2,040	13,260	10,786

Alcohol Use Disorder	NA*	NA*	2,114	1,173	2,470	2,184	NA*	NA*	2,264	1,358	2,870	2,199
Substance Use Disorder	NA*	NA*	2,265	1,517	1,799	2,098	NA*	NA*	3,799	2,926	4,250	4,058
Anxiety	NA*	NA*	5,124	4,639	6,279	6,279	NA*	NA*	5,726	5,265	7,537	7,416
Depression	NA*	NA*	3,782	2,874	6,007	5,867	NA*	NA*	3,191	2,272	5,637	4,656
Mood Disorder	NA*	NA*	6,371	4,900	9,399	8,891	NA*	NA*	5,607	4,410	8,375	7,297
Disorders diagnosed young	1,983	1,394	289	212	170	112	2,480	2,219	307	244	163	188
Visits per 1,000 per year												
Emergency Department	328	216	335	257	288	237	375	188	360	217	332	216
Emergency Department (SM)	13	20	26	21	31	39	20	7	32	12	45	36
Inpatient Stays	70	53	267	319	299	245	60	49	231	300	234	190
Inpatient Stays (SM)	14	7	43	24	45	32	11	5	37	21	37	21
Outpatient visits per person per year												
Total Outpatient	3.4	4.1	4.1	4.6	6.7	7.3	3.9	5.2	4.5	5.5	7.6	8.2
Outpatient (SM)	0.2	0.2	0.3	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.5	0.4

* We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation

For these identified records, indicator variables were created to identify type of medical claims inpatient, outpatient, and emergency department (ED) visits as well as prescription drugs, both overall and for visits related to substance use and mental health disorders (650-663, 670). We additionally obtained information on the age of the subscriber associated with each record. Because we did not have access to Medicare records, and did not include dual eligible participants due to the high likelihood of pre-existing medical conditions and smaller sample size, our sample does not include adults aged 65 or older. Age in years was defined as the calculated age on January 1, 2009 and January 1, 2013, and stratified into three age cohorts, 5-17, 18-44, 45-64 years.

Statistical analyses

Our focus is on the rate of diagnoses for the hypothesized conditions. We first assess whether there were significant changes in utilization overall between the baseline and TNNIS use periods and whether the observed changes differed by neighborhood (i.e., exposure) after considering other changes over time between these neighborhoods. We use Poisson regression (see equation 1) to model the number of overall and substance use and mental health related inpatient, emergency department and outpatient visits for those months in which participants were enrolled in Medicaid.

For our primary analyses, we use logistic regression (see equation 2) to examine the odds of receiving a diagnosis for the hypothesized conditions. Before implementing these regression analyses, we examined trends in socio-demographic characteristics as well as trends in Medicaid enrollment to ensure that no divergent patterns were noted around 2012. Because racial composition varied somewhat between the two neighborhoods (Table 1), we controlled for race in our analyses to ensure that compositional changes by race did not influence the analysis. We also stratified by age so that we could better test our *a priori* hypotheses by condition. For chronic diseases, i.e. cardiovascular disease, we adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016 (TNNIS implementation) to allow for lag time in disease manifestation.

$$\log\left(E(Y \mid \boldsymbol{x})\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (1)$$

$$where\ Y = number\ of\ Medicaid\ claims\ for\ condition\ of\ interest$$

$$offset = number\ of\ Medicaid\ enrollment\ months$$

$$\log\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_3, \qquad (2)$$

$$where\ p = \Pr(Y = 1)\ is\ the\ probability\ of\ having\ Medicaid\ claim\ for\ condition\ of\ interest$$

Here, x_1, was the indicator for neighborhood exposure condition (Sunset Park=0 vs Flushing=1); x_2, indicated implementation period (pre-implementation=0 vs TNNIS implementation=1); and x_3, race/ethnicity group membership (Asian=1, Black=2, Hispanic=3, White=4 [reference], Other=5, Unknown=6).

Patient and Public Involvement

The research question was inspired by the work of a non-profit community organization called Queens Quiet Skies that works to mitigate airplane noise. One of the coauthors of the paper was a member of this organization and obtained the Freedom of Information Act requests for Federal Aviation Administration documents. These documents were used to identify the treatment census tracts and measuring the level of airplane noise exposure.

Results

Participants were generally similar across both groups over the two points in time (Table 1), but health care utilization varied over time by age group and treatment status.

The increased use of the TNNIS climb occurred in 2012.[27] Prior to that date the climb was only used for the US Open or unexpected weather/runway repairs.[27] We were only able to obtain data on TNNIS departures after the New York Port Authority's Fiscal Year 2013 because the Port Authority indicated that the earlier data had been lost. There were roughly 1,278 TNNIS departures/year on average during US Open events in the 2013-2019 period, providing a point of reference. Since 2013, the total annual number of TNNIS climbs ranged from between 9,349 and 29,676, with an average of 18,653/year. The DNL figures (Figure 1) reflect the average noise exposure by census tract across the 2013-2019 period, and may not reflect the actual change in aircraft noise in Flushing, NY in the pre-2012 and post-2012 periods.

Overall medical utilization

Table 2 provides results from regression models assessing period-related changes in medical utilization and diagnoses. The effects of the change in flight patterns on overall utilization were inconsistent across types of utilization and age. Overall, outpatient visits increased slightly in Flushing relative to Sunset Park for those aged 18-44 (rate ratio [RR] = 1.04, 95% CI = 1.04, 1.05). Prescription drug claims also increased by a similar amount for this group (RR = 1.06, 95% CI = 1.06, 1.06). However, outpatient visits and prescription drug use for children in Flushing aged 5-17 (outpatient RR=0.86, 95% CI = 0.85, 0.87; prescription drug claims RR = 0.94, 95% CI = 0.94, 0.95) as well as for older adults 45 – 64 declined (outpatient RR=0.92, 95% CI = 0.92, 0.93; prescription drug claims RR = 0.93, 95% CI = 0.92, 0.93).

Table 2 – Model Results and 95% Confidence Intervals

	Rate Ratios from the Difference in Difference Poisson Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	0.92 (0.83, 1.03)	1.05 (1.02, 1.08)	0.93 (0.88, 0.97)
Emergency Department Visits	1.31 (1.24, 1.37)	1.45 (1.41, 1.49)	1.16 (1.11, 1.21)
Outpatient Visits	0.86 (0.85, 0.87)	1.04 (1.04, 1.05)	0.92 (0.92, 0.93)
Pharmacy Claims	0.94 (0.94, 0.95)	1.06 (1.06, 1.06)	0.93 (0.92, 0.93)
	Rate Ratios from the Difference in Difference Poisson Model Substance Use and Mental Health Related		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Inpatient Visits	NA*	1.11 (1.01, 1.22)	1.19 (1.04, 1.36)
Emergency Department Visits	4.11 (3.28, 5.16)	2.46 (2.20, 2.76)	1.48 (1.31, 1.67)
Outpatient Visits	1.12 (1.09, 1.16)	0.93 (0.92, 0.95)	0.87 (0.85, 0.89)
	Odds Ratios from the Difference in Difference Logistic Model		
	Age 5 - 17	Age 18 - 44	Age 45 - 64
Insomnia	1.64 (1.12, 2.39)	1.17 (1.09, 1.26)	1.18 (1.09, 1.28)
Cardiovascular Disease**	NA*	1.45 (1.30, 1.62)	1.15 (1.07, 1.25)
Alcohol Use Disorder	NA*	0.97 (0.86, 1.11)	1.16 (0.99, 1.35)
Substance Use Disorder	NA*	0.92 (0.83, 1.03)	1.24 (1.07, 1.44)
Depression	NA*	1.12 (1.02, 1.24)	1.20 (1.08, 1.33)
Anxiety	NA*	1.02 (0.95, 1.10)	1.01 (0.92, 1.11)
Mood Disorder	NA*	1.03 (0.95, 1.10)	1.10 (1.00, 1.20)
Disorders diagnosed young	0.80 (0.66, 0.97)	0.99 (0.72, 1.37)	0.56 (0.31, 1.04)

282

283 *These diseases and conditions are rare or difficult to diagnose in children.

284 **We adopted a longer follow-up period 2008-2011(pre-implementation) and 2013-2016

285 (TNNIS implementation) to allow for lag time in disease manifestation

286 While the general pattern for outpatient visits indicates decreased medical utilization in Flushing compared to Sunset Park over time, emergency department visits in Flushing increased in the post TNNIS period among all age groups. For ages 5-17, the RR was 1.31 (95% CI= 1.24, 1.37); for ages 18-44, the RR was 1.45 (95% CI = 1.41, 1.49); and for ages 45-64, the RR was 1.16 (95% CI = 1.11, 1.21). Substance use and mental health-related emergency department visits also increased in Flushing in the post period relative to Sunset Park, with rate ratios ranging between 2.5 to 4.1. For ages 5-17 RR= 4.11 (95% CI= 3.28, 5.16); for ages 18-44 RR = 2.46 (95% CI = 2.20, 2.76); and for ages 45-64, RR = 1.48 (95% CI = 1.31, 1.67).

294 Relative to Sunset Park, inpatient visits in Flushing also show statistically significant increases for overall visits for ages 18-44 (RR=1.05, 95% CI = 1.02, 1.08). However, statistically significant decreases were observed for ages 45-64 (RR=0.93, 95% CI = 0.88, 0.97).

297 Changes by diagnosis

298 Relative to Sunset Park, implementation of the TNNIS climb was associated with increases in insomnia diagnoses, particularly for children. For example, the crude prevalence of insomnia for children increased by 57% from 398 per 100,000 in Flushing, compared to a 6% decrease from 477 per 100,000 in Sunset Park. For children in this age group, the odds ratio (OR) for insomnia was 1.64 (95% CI =1.12, 2.39). For older ages, the effect sizes were somewhat less striking (i.e., for the 18-44 age group, the OR was 1.17 [95% CI = 1.09, 1.26], and for ages 45-64 the OR = 1.1 [95% CI = 1.09, 1.28]).

305 Cardiovascular disease diagnoses increased significantly in Flushing relative to Sunset
306 Park in the post-2012 period. For 18-44-year-olds, the crude prevalence of cardiovascular disease
307 increased in both neighborhoods due to aging of the samples, by 83% from 1,955 per 100,000 in
308 Flushing and by 29% from 1,576 per 100,000 in Sunset Park. The OR for cardiovascular disease
309 diagnoses in Flushing relative to Sunset Park in this age group was 1.45 (95% CI = 1.30, 1.62).
310 For 45-64-year-olds, , the crude prevalence increased by 33% from 9,934 per 100,000 in
311 Flushing and 19% from 9,073 per 100,000 in Sunset Park. For this age group, the OR was 1.15
312 (95% CI = 1.07, 1.25). Substance use disorder only increased significantly for the 45-64 age
313 group in Flushing relative to Sunset Park (OR =1.24, 95% CI=1.07, 1.44).

314 Figure 2 shows the monthly prevalence of insomnia and cardiovascular disease diagnoses
315 for the 45-64 age group. Age is measured at the beginning of each period, January 1, 2009 for
316 the pre-period and January 1, 2013 for the post period. The numerator is the number of unique
317 individuals with one or more diagnosis from inpatient, emergency room or outpatient claims and
318 the denominator is the number of Medicaid-enrolled patients. The trends of both conditions
319 increased throughout the study periods, because people are getting older, but Flushing showed
320 increases that were larger in magnitude in the post period relative to Sunset Park.

321

322 Figure 2 – Prevalence of insomnia and cardiovascular disease diagnoses per 100,000 among 45-
323 64 age group

324 [insert figure 2 here]

325 Results for other conditions were more mixed. Clinical depression diagnoses increased
326 for the two older age groups (ages 18-44 OR = 1.12, 95% CI = 1.02, 1.24; ages 45-64 OR = 1.20,
327 95% CI = 1.08, 1.33). Broader mood disorder diagnoses, however, only showed statistically

significant increases for the 45-65 age group (OR = 1.10, 95% CI = 1.00, 1.20). For 5-17-year-olds, developmental disorder diagnoses significantly decreased (OR=0.80, 95% CI = 0.66, 0.97) in Flushing relative to Sunset Park after the implementation of TNNIS.

Discussion

We find that increases in airplane noise at DNL levels greater than 55 were associated with increases in insomnia, depression, substance abuse, and cardiovascular disease across most age groups. These diagnoses are generally consistent with our *a priori* hypotheses regarding the relationship between exposure to airplane noise and health.[3,6,8,9,12,13,30,31] Specifically, airplane noise may produce disruptions in sleep and psychological stress, thereby producing neuroendocrine disruptions that lead to mental health disorders and cardiovascular disease.

The biological pathways through which airplane noise impacts health have been elucidated.[9-14] Numerous associational studies suggest that airplane noise produces real-world health impacts, and experimental animal models show a wide range of health impacts associated with noise-induced stress as well.[3-9,11-13,15-18,32] Our study adds quasi-experimental evidence in humans to this substantial body of research showing that increasing airplane noise will have detrimental health impacts on communities surrounding airports. The magnitude of our findings is not strictly comparable to those in associational studies because lagged health effects (e.g., the time required for psychological stress to manifest as cardiovascular disease) tend to mute the measured impacts.

Nevertheless, the magnitude of the impact of airplane noise on the health outcomes we observe are generally in line with previous work. For instance, an earlier analysis of associational studies of the health impact of aircraft noise in Flushing, NY estimated that aircraft noise would produce a weighted increase in cardiovascular disease of 14% (RR = 1.14, 95% CI = 1.08, 1.22)

351 and a weighted increase in anxiety of 79% (RR = 1.79, 95% CI = 1.0-3.1).[11,24] We observe an
352 odds ratio for cardiovascular disease among 18-64-year-olds in the range of 1.12 to 1.40. While
353 the studies examine incident cardiovascular disease and we measure both incident and prevalent
354 cardiovascular disease, it is reasonable to assume that the OR we estimate does not greatly
355 overestimate the adjusted RR computed using associational studies.[37]

356 In the international literature, the self-reported annoyance, health, health-related quality
357 of life, and cardiovascular disease rates for those who live close to airports is significantly lower
358 than for matched individuals living in quieter areas.[38-40] In this literature, these latter findings are
359 particularly true for noise-sensitive individuals.[38,39] This suggests that self-selection by noise
360 may mute previously observed effects in ecological studies, which control for socio-economic
361 status but not always noise sensitivity. One strength of our study is that the change in aircraft
362 noise was exogenous and moving out of a neighborhood requires time and effort.

363 Our study was subject to a number of limitations. First, the health effects in a
364 predominantly Chinese-American population may not be generalizable to other populations.
365 Chinese-Americans in New York City are unusually healthy.[41] Medicaid data also present unique
366 challenges. Participants can enter and exit the program, for example. If there are more
367 participants exiting the program in one area relative to another, the observed outcomes will also
368 change. We addressed this problem by adjusting for the months a participant was enrolled in
369 Medicaid within a calendar year.

370 Next, we use DNL as a measure. Frequency of noise exposure may be superior at
371 predicting health outcomes, but frequency data were not available. Finally, it is possible that the
372 change in neighborhood composition over time differed before and after the implementation of
373 year-round TNNIS departures in Flushing relative to Sunset Park. However, we did not observe

any trends in the available data that suggested this was the case, and there were no major events in 2012 that clearly serve as an alternative causal factor for either the primary or unexpected findings. Moreover, our findings apply only to the zip codes directly under the DNL zones defined by our analysis.

Cost-effectiveness analyses (based partly on earlier associational data) show that the benefits of noise-mitigation strategies (reduced illness and discomfort) tend to outweigh the costs.[24,42] Given that these earlier studies did not include the full range of health outcomes that we measure here, it is likely that these studies understate the already substantial benefits of aircraft noise mitigation strategies.

Much more comprehensive quasi-experimental and economic analyses are required to determine the extent to which policymakers may wish to act. The costliest options—building airports far from populated areas and providing high speed transit and freeways—can increase the cost of mitigation by billions of dollars.

Research Ethics Approval

This study is approved by the Institutional Review Board at New York University Washington Square under IRB-FY2016-1101.

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Contributorship Statement

Ms. Scarlett Sijia Wang, Dr. Sherry Glied, Dr. Sharifa Z. Williams and Dr. Peter Meunnig approved the final draft and agreed to be accountable for all aspects of the work. Ms. Scarlett Sijia Wang contributed to study design, data linkage, analysis, interpretation of the data, drafting the methods and results sections. Dr. Sherry Glied contributed to the acquisition of data, study design, analysis, and interpretation of data. Dr. Sharifa Z. Williams contributed to data analysis and interpretation of data. Dr. Peter Muennig contributed to study conception, study design, analysis, interpretation of data and drafting the introduction and discussion sections. Though Mr. Brian Will passed away prior to the submission of the manuscript, he had significant contributions in the study conception, the acquisition of data and sample identification.

Wang, Scarlett (proxy) (contact); Glied, Sherry; Williams, Sharifa; Will, Brian; Muennig, Peter

Competing interests

At the time of the study, Mr. Brian Will worked at a non-profit organization called Queens Quiet Skies who are a grass-roots group aiming to address airport noise.

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Data Sharing

418 We used individual-level claims data that contain protected Patient Health Information (PHI). Therefore, the data cannot be made available publicly as required by the Health Insurance Portability and Accountability Act (HIPPA).

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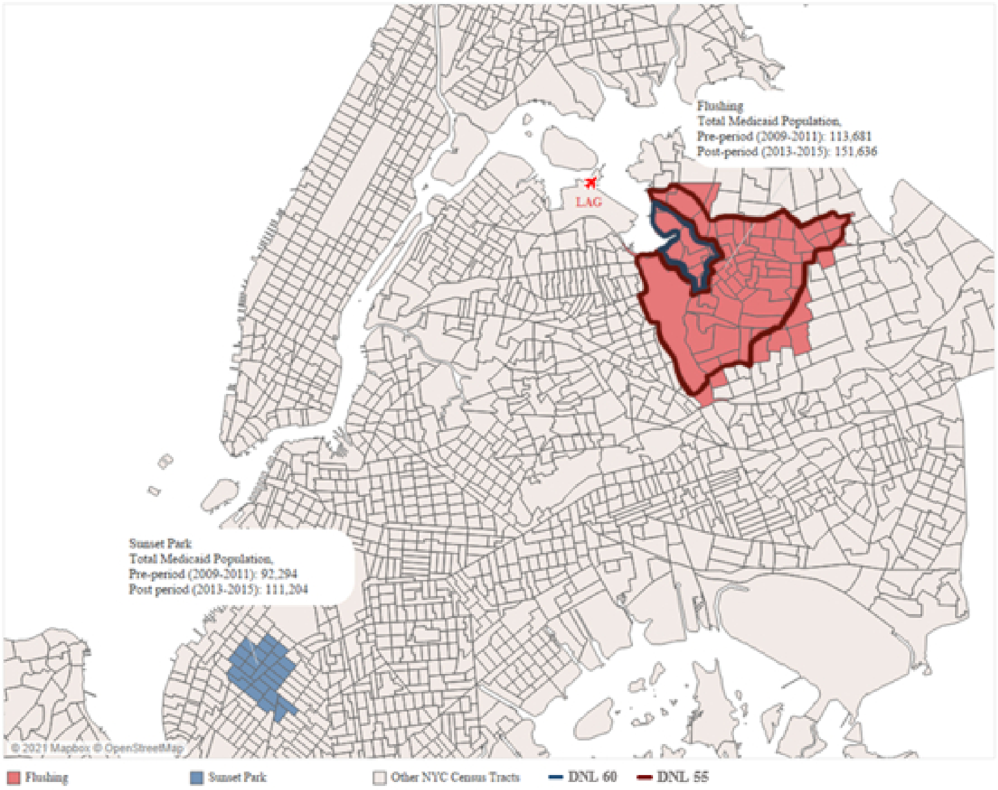

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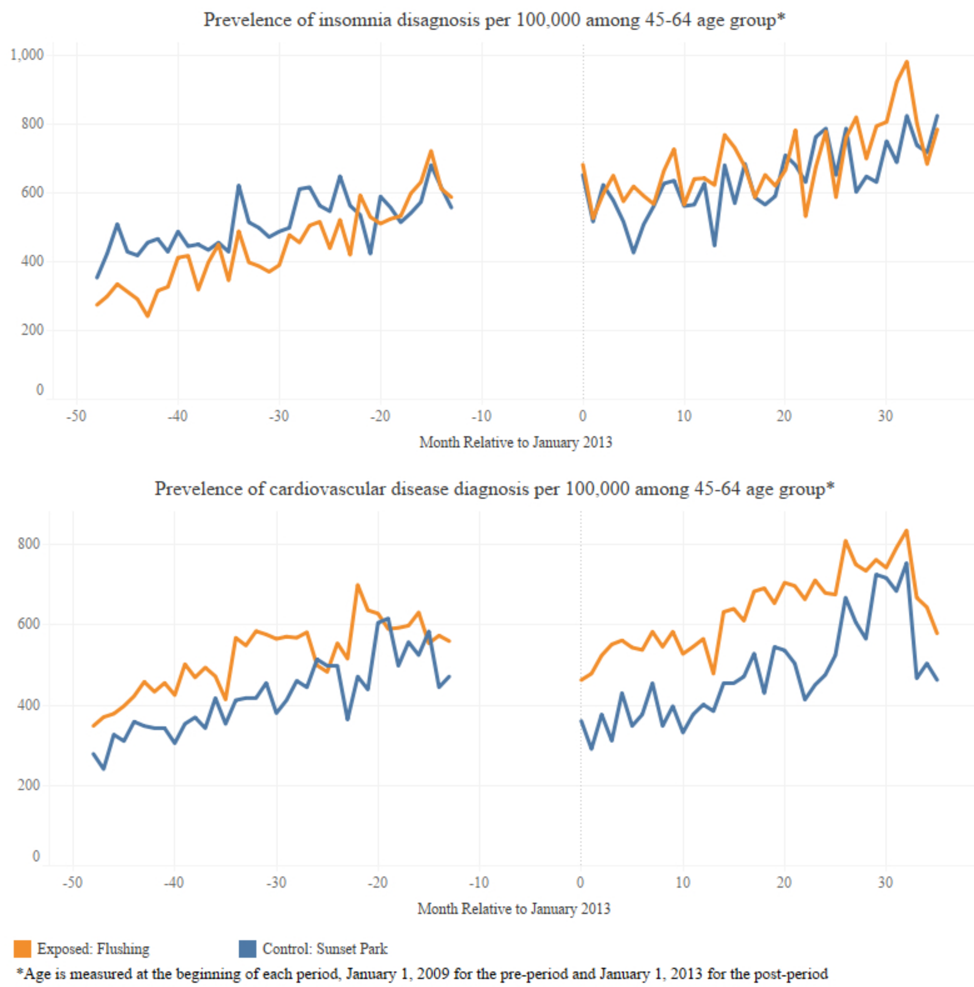

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2-3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4-6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up (*b*) For matched studies, give matching criteria and number of exposed and unexposed	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4
Bias	9	Describe any efforts to address potential sources of bias	7, 11
Study size	10	Explain how the study size was arrived at	8, 14-15
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	7-8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	8, 14-15
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	8,14-15
Outcome data	15*	Report numbers of outcome events or summary measures over time	8-11, 14

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (*b*) Report category boundaries when continuous variables were categorized (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8-11, 14-19
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	11-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Supplemental material, acknowledgements

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.